TECHNICAL REPORT 079

Desktop Watershed Characterization Methods for British Columbia

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BRITISH COLUMBIA

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Robin Pike and David Wilford

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INTRODUCTION

In recent years, the accessibility of online mapping tools and GIS information has dramatically increased. As a result, it is now possible to remotely gather information about a watershed's potential disturbance, hydrologic, and climatic characteristics. Watershed characterizations are often used when developing plans for monitoring, research projects, water quality objectives, industrial use, and other end uses, such as fisheries restoration or small-scale power projects. A watershed characterization is distinctly different from a watershed assessment that develops specific disturbance indicators and then ranks them accordingly. Desktop characterization of a watershed in advance of fieldwork allows for improved planning of field activities and/or monitoring projects, thereby increasing efficiency and reducing costs.

The purpose of this report is to highlight current sources of online tools and watershed information, provide a template of potential disturbance drivers to consider, and ultimately create a list of questions that can be used to characterize a watershed's hydrologic regime. This document does not specify the development of watershed analysis style indicators for the purposes of watershed assessment. This technical report was developed to aid in the descriptive, hydrologic characterization of watersheds in British Columbia. The content was originally developed as a template for preparing hydrology descriptions when planning water quality or water quantity monitoring projects. As a result of the peer review process, however, the content was expanded to allow a broader application of the featured techniques.

This document is intended for anyone who wishes to use a desktop approach to initially characterize a watershed. It is important to note that some of the featured desktop methods may not work at certain mapped scales, and highlighted layers may be limited in coverage in some areas of the province. The techniques featured within are intended to be a first-order approximation of characterization, and should therefore not displace the need for more precise information when required.

This report is divided into three sections: (1) a watershed characterization template, (2) a narrative of working through the template using the Carnation Creek watershed on Vancouver Island, and (3) an example watershed characterization report write-up.

PART 1: WATERSHED CHARACTERIZATION TEMPLATE

1.1 Information Resources

In recent years, the availability of online mapping tools and provincial information has dramatically increased. It is because of these resources that desktop watershed characterizations are possible. The primary information resources used in the template include the following:

Provincial information and mapping tools

- Province of British Columbia Web Map Services (WMS): (to obtain Google Earth layers): www.data.gov.bc.ca/dbc/geo/wms/index.page
- B.C. Freshwater Atlas: www.ilmb.gov.bc.ca/geobc/FWA_data

- BC Water Resources Atlas: www.env.gov.bc.ca/wsd/data_searches/wrbc/index.html
- iMapBC: http://maps.gov.bc.ca/ess/sv/imapbc/
- Natural Resources Canada—GeoGratis (maps, publications, data): http://geogratis.gc.ca/geogratis/
- University of New Hampshire Keyhole Markup Language (KML) Tools : http://extension.unh.edu/kmlTools/index.cfm
- Earth Point—Tools for Google Earth: http://earthpoint.us/Shapes.aspx
- Environmental Monitoring System (EMS) (water quality): www.env.gov.bc.ca/epd/wamr/ems_internet/
- Forest health (insects, diseases, and abiotic influences, including wildfire and landslides) information: www.for.gov.bc.ca/hfp/health/overview/overview.htm
- University of British Columbia Geographic Information Centre Air Photo Collection and Services: www.geog.ubc.ca/resources/gic/air_photo.html

Historical climate data

- Provincial Climate Data Set (PCDS) Portal (includes Environment Canada, B.C. Ministry of Forests, Lands and Natural Resource Operations, B.C. Ministry of Transportation and Infrastructure, and fire weather stations): www.pacificclimate.org/tools-and-data/pcds-portal
- Environment Canada Climate Data website (for historical data, climate normals adjusted, and homogenized Canadian climate data): http://climate.weather.gc.ca/data_index_e.html
- B.C. River Forecast Centre (manual and automated snow survey data): http://bcrfc.env.gov.bc.ca/
- Climate data through Climate Western North America (WNA): www.genetics.forestry.ubc.ca/cfcg/climate-models.html

Climate change information

- Climate Western North America (WNA): www.genetics.forestry.ubc.ca/cfcg/climate-models.html
- Pacific Climate Impacts Consortium (PCIC) Regional Analysis Tool: http://tools.pacificclimate.org/select
- PCIC Plan2Adapt: http://pacificclimate.org/tools-and-data/plan2adapt

Hydrometric data / tools

- Water Survey of Canada (WSC), Real-time Hydrometric Data: www.wateroffice.ec.gc.ca/index_e.html
- Northeast Water Tool: http://geoweb.bcogc.ca/apps/newt/newt.html
- U.S. Army Corps of Engineers hydrologic statistical analysis program HEC-SSP: www.hec.usace.army.mil/software/hec-ssp/

Hydrology references

- *Compendium of Forest Hydrology and Geomorphology in British Columbia*: www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh66.htm
- *Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska*: http://warnercnr.colostate.edu/~leemac/publications/MonitoringGuidelinestoEvaluateEffectsofForestryActivitiesonStreams.pdf

1.2 Previous Studies

There are many databases that contain information on watersheds in British Columbia. For example, the Ecological Reports Catalogue (EcoCat) contains more than 900 entries regarding British Columbia watersheds (www.env.gov.bc.ca/ecocat/). Water quality data can be located in EMS: www.env.gov.bc.ca/emswr/. Previously completed watershed/terrain assessments by the forest industry or assessments completed for other industries are also sometimes available on EcoCat.

Watershed assessments can be accessed in EcoCat by accessing the main page, clicking "Public," then "Advanced Search," then scrolling to the bottom of the page and under "Water Information," clicking "Watershed Assessments Studies." Studies can also be searched spatially by selecting the "Search for reports using a map" option at the bottom of this page. More detailed instructions on how to access watershed assessments in EcoCat are provided by Carver (2008).

GeoGratis (Natural Resources Canada) provides an online database that allows users to spatially search for maps, data, and publications (http://geogratis.gc.ca/geogratis). Google and Google Scholar are also good places to check for publications associated with any location of interest.

1.3 Maps

To characterize a watershed, a map should be created to display, at minimum:

a. watershed boundaries;
b. topographic contours;
c. water features—streams, lakes, wetlands;
d. roads; and
e. monitoring site locations.

Information from the map can be used to describe the following characteristics:

Watershed size (ha or km^2)	Length of watershed (km)
Location	Width of watershed (km)
Relief (m)	Number of stream crossings
Biogeoclimatic zone(s)	Length of mainstem (km)
Land uses (%)	Length of tributaries (km)
Land ownership	Total length of all channels (km)
Tree Farm Licence (TFL) or Timber Supply Area (TSA)	Length of roads (km)
	Lake area (ha or km^2)
Forest District/Region	Wetland area (ha or km^2)
Total disturbed area (km^2)	Glacier area (ha or km^2)

To ensure adequate detail is provided, the map should be printed in a 28 × 43 cm (11 × 17") or larger format, and the following characteristics should be identified: point source discharges, stream crossings, fans, mass movements such as landslides, and various land uses throughout the watershed (e.g., agriculture, forestry, industrial, urban). Any features that might influence hydrology in the watershed should also be highlighted (e.g., diversions, dikes, springs). This map should then be included as an appendix along with a smaller map.

1.4 Air Photos/Remotely Sensed Images

If the water body is wide enough, air photos from two or more time periods can be used to identify changes in stream channels (see Hogan and Luzi 2010) and/or landscapes. While the causal mechanisms may not be apparent, visible changes can provide information on likely parameter sensitivity and recovery through time (Figure 1). Air photos can be located and ordered via www.geog.ubc.ca/resources/gic/air_photo.html.

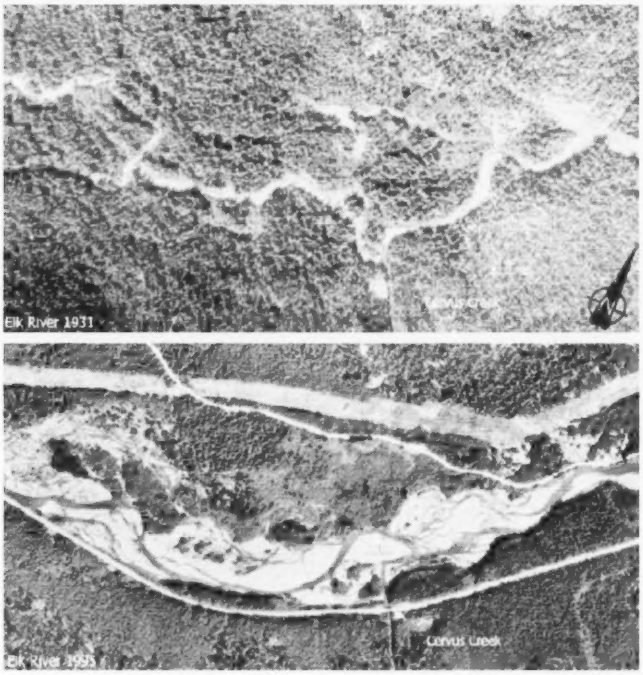

FIGURE 1 *The lower section of Elk River on Vancouver Island changed from a single-thread channel (top photo) to a multi-thread channel (bottom photo) following valley-flat forest harvesting and roading in the 1940s. (Image compilation: M. Miles. Image from Polster et al. 2010, Figure 18.3).*

1.5 Watershed Climate

Local climate data (see section 2 of this report) or information from Climate WNA can be used to describe the following characteristics:

a. mean annual precipitation;
b. monthly or seasonal precipitation;
c. monthly or seasonal snow;
d. percentage of precipitation as snow;
e. mean annual and mean monthly air temperatures; and
f. variability of climate variables (e.g., seasonal, annual).

If the watershed has a large elevation range, upper and lower sites can be selected or a median elevation value can be used to characterize climate in the watershed.

Climate WNA (Google Map based web version) can also be used to investigate a range of possible future climates for the watershed.

1.6 General Hydrology and Drainage Characteristics

The following questions can assist in describing the hydrology and drainage characteristics of a watershed or monitoring site. It may not be possible to answer some questions using desktop-derived data; however, any outstanding questions can be used to guide future field investigations. Sections 2 and 3 of this report show how the following questions can be answered with collected desktop data.

Hydrometric data can be gathered from a WSC station or closest alternative (e.g., Northeast Water Tool) and used to determine:

- mean annual discharge;
- mean and median flows (based on daily data), annual flow, and monthly flows; and
- maximum and minimum values by month or average maximum/minimum values sorted by month.

Consideration should then be given to:

- calculating exceedance probabilities (percentile flows) for peak and low flows; and
- estimating the expected lowest 7-day average discharge that occurs once every 5 or 10 years.

Address the following questions:

a. Is the water system regulated or natural? Are any diversions present (list numbers/types)?
b. What is the expected hydrologic regime (rain, snow, hybrid, glacial) of the area?
c. In terms of water storage and release components, what is the role of wetlands, lakes, dams/diversions, glaciers, preferential flow, and groundwater in shaping daily and/or seasonal discharge?
d. Is runoff rapid or a prolonged event? Does runoff occur immediately after a storm or is it delayed? What is the primary hydrologic driver (snow, rain, groundwater, glaciers, or convective storms)?
e. What is the seasonality of flow? Do low flows occur only in specific seasons or at any time during the year?
f. Does streamflow ever become intermittent along the channel profile? Have zero-flow conditions been measured in the watershed?
g. Are drainage diversions, roads, ditches or other impervious surfaces affecting runoff patterns and timing?
h. Is information on groundwater/surface water interactions available (e.g., observation wells or water level trends: www.env.gov.bc.ca/wsd/data_searches/wells/index.html)?
i. Is bedrock geology influencing discharge (e.g., sinking or losing streams)?
j. Do processes involving ice (e.g., glaciers, river ice, and permafrost) in the watershed affect water quality/quantity parameters?

1.7 Sediment, Stream Channels, and Sediment Yield Potential

The following questions can assist in describing the sediment, stream channel, and sediment yield potential characteristics of a watershed or monitoring site. It may not be possible to answer some questions using desktop-derived data; however, any outstanding questions can be used to guide future field investigations. Sections 2 and 3 of this report show how the following questions can be answered with collected desktop data.

a. Have there been any recent extreme floods? If not, how long ago was the last major flood?
b. Is there evidence of past/recent landslides connected to streams in the watershed? Have there been any recent large mass movement events in the watershed? Is there any obvious evidence of past/recent landslides connected to streams?
c. Are slopes or existing landslides directly connected to the water body of interest?
d. Does the watershed have the following? How might these influence the timing and fate of sediment input?
   - active fans/active fluvial units
   - stream crossings adjacent to erodible materials
   - landslide-prone terrain (i.e., gullies, gentle over steep, steep or unstable terrain; see Geertsema et al. 2010; Jordan et al. 2010)
   - easily erodible soils (e.g., fine lacustrine deposits)
   - historic channel widening/alteration of riparian areas
   - prominent sources of surface eroded sediment (i.e., roads, fine-grain soils)
   - chronic, within-channel sediment sources
e. Does the stream channel show signs of high sediment loading or instability (see Hogan and Luzi 2010)?
f. Based on the above, qualitatively, does the watershed have a high or low sediment yield potential?

1.8 Land Uses and Natural Disturbances Checklist

The natural disturbance drivers in the watershed (e.g., forest health, climate change, terrain) that could affect discharge and/or water quality should be described. What is the approximate footprint and location of each in the watershed? The major land uses in the watershed (e.g., forestry, agriculture, range, recreation, parks, protected areas, mining, oil and gas, urban, power/run-of-river projects) should also be described. What is the approximate footprint and location of each in the watershed (e.g., clearcuts are distributed over 50% of the watershed above 500 m)?

If stream discharge or water quality is the focus of the watershed characterization, Table 1 can be used to identify the drivers that may influence the monitoring site and/or parameters of interest. Will any of these drivers compromise or confound the monitoring of parameters that have been selected? Note: accidental chemical spills (i.e., fuel, oil, hydraulic fluid, and other chemicals) are not covered in this template.

TABLE 1 *Water quality parameters and associated natural and anthropogenic drivers*

Water quality parameters	Disturbance drivers
Stream discharge	**Natural systems:** weather, climatic variability, natural alterations to vegetation and ground surfaces, high tides, wildfire, natural dam failures (e.g., beavers, landslides, glacial outbursts), forest health, insects (e.g., mountain pine beetle)
	Specific drivers that can affect stream discharge in a watershed:
	Forestry: equivalent clearcut area, location of harvest, vegetation replacement, roads, stream crossings, altered drainage, soil disturbance
	Range: water extraction/diversions
	Agriculture: roads, water extraction/irrigation/diversions, vegetation alteration, dikes
	Urban: stormwater systems, roads, water extraction, percentage of impervious surfaces, dikes/dams, regulated systems, vegetation alteration
	Oil/gas extraction: roads, borrow pits, water extraction, vegetation alteration, drilling requirements, drainage diversions
	Mining: roads, drainage alterations, borrow pits, water extraction, vegetation alteration, tailing ponds (including seepage), open pit/underground workings drainage, channel diversions associated with works
	Power/run-of-river projects: flow impoundments (dams), penstock diversions, flow retention and release schedules
	Other: climate change, glacier recession, fisheries-related diversions
Sediment/turbidity	**Natural systems:** instream erosion, mass wasting, surface erosion from fine-grained materials, extreme runoff events, wildfire, forest health drivers
	Specific drivers that can affect sediment production in a watershed:
	Forestry: roads, road deactivation (level of), watershed restoration (level of), stream crossings, increased mass wasting, altered drainage, soil disturbance, removal of riparian vegetation, fan disturbance, industrial traffic
	Range: livestock near water bodies (pugging), removal of riparian vegetation
	Agriculture: certain tillage/crop practices, runoff over bare soil
	Urban: construction near waterways, stormwaters, roads
	Oil/gas extraction: roads, borrow pits, waste waters, construction activities
	Mining: tailings, roads, open pit excavations, placer and other operations, construction activities
	Recreation: motorized vehicles, jet boats
	Power/run-of-river projects: increased turbidity at penstock outlet, reduction in sediment loads due to upstream impoundments, lake drawdown and bank instability
	Other: gravel extraction, disturbed lake beds

TABLE 1 *Continued*

Water quality parameters	Disturbance drivers
Pathogens	**Natural systems:** wildlife (e.g., beavers, wolves, waterfowl), natural occurrence
	Specific drivers that can affect pathogen levels in a watershed: **Forestry:** site specific/camps **Range:** livestock near water bodies **Agriculture:** manure runoff, waste waters **Urban:** stormwater, septic/sewer, waste waters **Oil/gas extraction:** site specific with camps or operations **Mining:** sewage and putrescible waste **Recreation:** campsites/human wastes
Nutrients (e.g., phosphorus, nitrogen)	**Natural systems:** wildfire, widespread insect outbreaks, animals (e.g., salmon), forest health, mass wasting
	Specific drivers that can affect nutrient levels in a watershed: **Forestry:** vegetation clearing, vegetation replacement, herbicides, fertilizers, soil disturbance, soil erosion, prescribed burning, fire retardants and suppressants, blasting residue (e.g., nitrates from explosives), increased mass wasting **Range:** livestock near water bodies (manure), soil erosion **Agriculture:** fertilizers, herbicides, soil disturbance, manure runoff, waste water discharges, soil erosion and sediment delivery **Urban:** stormwater, fertilizers, septic/sewer, waste-water discharges, development that exposes soils **Oil/gas extraction:** sewage associated with camp or other operations, roads, activities that increase sedimentation **Mining:** sewage associated with camps, blasting residue (e.g., nitrates from explosives), soil erosion and sediment delivery **Recreation:** recreational vehicle sani dumps, brown/grey water discharges, campsite outhouses **Other:** any activity that alters background pH (e.g., some mining activities), increases erosion and sedimentation, or alters nutrient cycles (soil/vegetation)

TABLE 1 *Continued*

Water quality parameters	Disturbance drivers
Metals	**Natural systems:** natural metal-bearing rock, atmospheric deposition (e.g., mercury), runoff levels
	Specific drivers that can affect metal levels in a watershed:
	Forestry: fertilizers, herbicides, soil disturbance, road building
	Range: fertilizers, herbicides, soil disturbance
	Agriculture: fertilizers, herbicides, soil disturbance
	Urban: stormwater, sewer/septic, waste-water treatment, permitted discharges
	Oil/gas extraction: borrow pits, discharges and return flow associated with hydraulic fracturing practices that alter pH
	Mining: tailings (deposited at surface or in natural water bodies by historical operations), seepage from tailings impoundments and waste rock dumps, open pit/underground oxidation products, permitted discharges, and other mining activities or practices that alter pH of drainage
	Other: any activity that alters drainage and/or increases flow and drainage through metal-rich materials/soils, or practices that alter pH of drainage, other permitted discharges
Dissolved oxygen	**Natural systems:** low flows, anoxic environments, forest health
	Specific drivers that can affect dissolved oxygen levels in a watershed:
	Forestry: deposition of slash and organics in water ways, fertilization with phosphorus (P), alteration of stream temperatures, alteration of channel roughness
	Range: see "Water temperature"
	Agriculture: added organics (including runoff), fertilization with P, reductions in discharge, groundwater extraction
	Urban: reductions in flow, organics in stormwater, waste/septic discharges, groundwater extraction
	Oil/gas extraction: reductions in flow, groundwater extractions, drainage diversions to borrow pits
	Mining: reductions in flow, groundwater extractions, drainage diversions
	Power/run-of-river projects: upstream impoundments, flow release schedule
	Other: activities that lead to the addition of organic matter and/or wastes

TABLE 1 *Concluded*

Water quality parameters	Disturbance drivers
Water temperature	**Natural systems:** presence of wetlands/lakes, climatic variability, insects, wildfire, wildlife (e.g., beavers), forest health, natural events that alter riparian vegetation, streamflow, or channel conditions
	Specific drivers that can affect water temperatures in a watershed:
	Forestry: harvesting riparian areas, altered sediment and flow regimes, stream channel widening (sometimes historic), road/ditch drainage diversions
	Range: removal of riparian vegetation, stream bank alterations that cause channel widening
	Agriculture: reductions in surface flows, groundwater extractions, riparian/channel modifications/diversions
	Urban: reductions in surface flows, groundwater extractions, riparian modifications, drainage diversions
	Oil/gas extraction: reductions in flows, groundwater extractions, drainage diversions
	Mining: reductions in flows, groundwater extractions, drainage diversions, tailings impoundments, and process-water recycling
	Power/run-of-river projects: upstream impoundments, penstock return flow, hydro reservoir releases
	Recreation: riparian modifications
	Other: removal of wood from stream channels
pH	**Natural systems:** atmospheric deposition (precipitation), flow regime changes
	Specific drivers that can affect pH levels in a watershed:
	Agriculture: application of lime agents, water extraction from lakes with long residence times
	Urban: discharges, water extraction from lakes with long residence times
	Oil/gas extraction: discharges, flow back (water returned to the surface via hydraulic fracturing operations)
	Mining: permitted discharges, seepage from mine infrastructure (tailings ponds, ore stockpiles, waste rock dumps), and other discharges
	Recreation: water extraction from lakes with long residence times
Electrical conductivity	**Natural systems:** annual variability between different runoff storage reservoirs (i.e., snowpack, groundwater, surface, rain, glaciers)
	Specific drivers that can affect electrical conductivity in a watershed:
	Forestry: road de-icing, drainage diversions/alterations
	Agriculture: surface runoff, drainage diversions/alterations
	Urban: road and surface runoff, road de-icing operations, road salts
	Oil/gas extraction: hydraulic fracturing return flow (saline waters), drainage diversions/alterations
	Mining: permitted discharges, drainage diversions/alterations, other discharges
	Recreation: ski hill operations/road de-icing
	Other: runoff from airports, chemical discharges

Carnation Creek was chosen as an example watershed because it is well-studied, and template validation data would therefore be readily available (to ensure that the derived template values were close to the true values). For the purposes of this example, however, only template-derived data for Carnation Creek are used in this document. The information presented below was gathered using the template only.

2.1 Previous Studies: Search Result

EcoCat

- Ten reports on a wide variety of subjects related to Carnation Creek were discovered in EcoCat.
- No watershed assessments for Carnation Creek were available in EcoCat, although one watershed assessment was available for the adjacent Sarita River watershed.

Environmental Monitoring System: Three EMS entries (E280499, E280019, and E27524) were found in the EMS database. Two of these entries revealed the presence of WSC weir installations on Carnation Creek. Knowledge of the weirs was an important flag to later search the WSC historic and current data website. The other EMS number appeared to be a short-term provincial water quality monitoring site, although no data were retrievable from the database.

A Google search for Carnation Creek yielded a number of websites that had information and reports on the watershed. A Google Scholar search also revealed many publications on various aspects of Carnation Creek. The watershed is used for researching fish-forestry interactions, and a number of organizations are involved (e.g., Fisheries and Oceans Canada, Province of British Columbia). The current organizational lead listed on the website is the British Columbia Ministry of Forests, Lands and Natural Resource Operations (FLNRO) (however, it is actually the B.C. Ministry of Environment [MOE]. Following up with Peter Tschaplinski (the listed contact) was flagged as a priority prior to moving forward with the remainder of the template.

2.2 Map Creation

Google Earth and the information layers available from the B.C. Government Web Map Services were used to create the following maps. Google Earth was used because of its functionality and widespread availability.

First, the *B.C. Web Map Library* layers were downloaded and saved to the computer. Watershed layers were then opened and saved into the Google Earth *My Places* folder, and the watershed was located and roughly centred on the computer screen. Under the *BCGov Base Mapping WMS* folder, all boxes in the *Base Mapping 1:20,000* subfolder were selected (including the *Transportation 20K* layer, which showed portions of the road coverage). Elevation contours were lightened (or darkened) by right clicking on the folder properties (*elevation contours*) and sliding the transparency button left towards "Clear" until the desired level was reached (Figure 2). A watershed identifier could also be added using the place marker button (push pin icon) on the top of the page.

Watershed boundaries Watershed boundaries were drawn using the *Add Polygon* tool and making this a permanent layer in *My Places* in Google Earth. Predefined boundaries were available under a different folder (*BCGov*

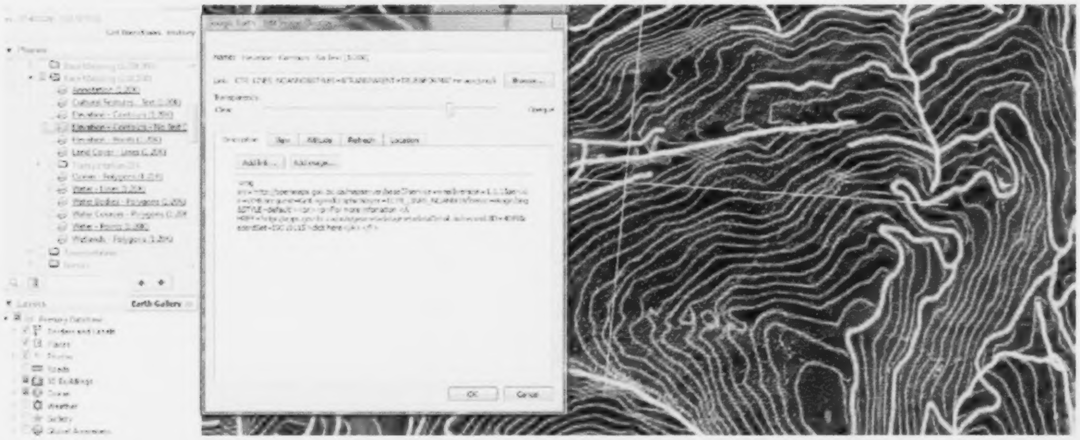

FIGURE 2 *Google Earth screen shot of modifying elevation contour properties.*

Base Mapping Corporate Watershed WMS). In this folder, all layers in either *Watershed Atlas 1:20,000* or *Watershed Atlas 1:50,000* can be selected depending on the size of the watershed. These polygons are the component watersheds that are predefined. Stream channels (water lines) should be displayed while performing this step. Using the *Add Polygon* tool, the outside edge of all the smaller component basins that comprised the watershed were traced and saved to *My Places* (Figure 3). The same process was applied to

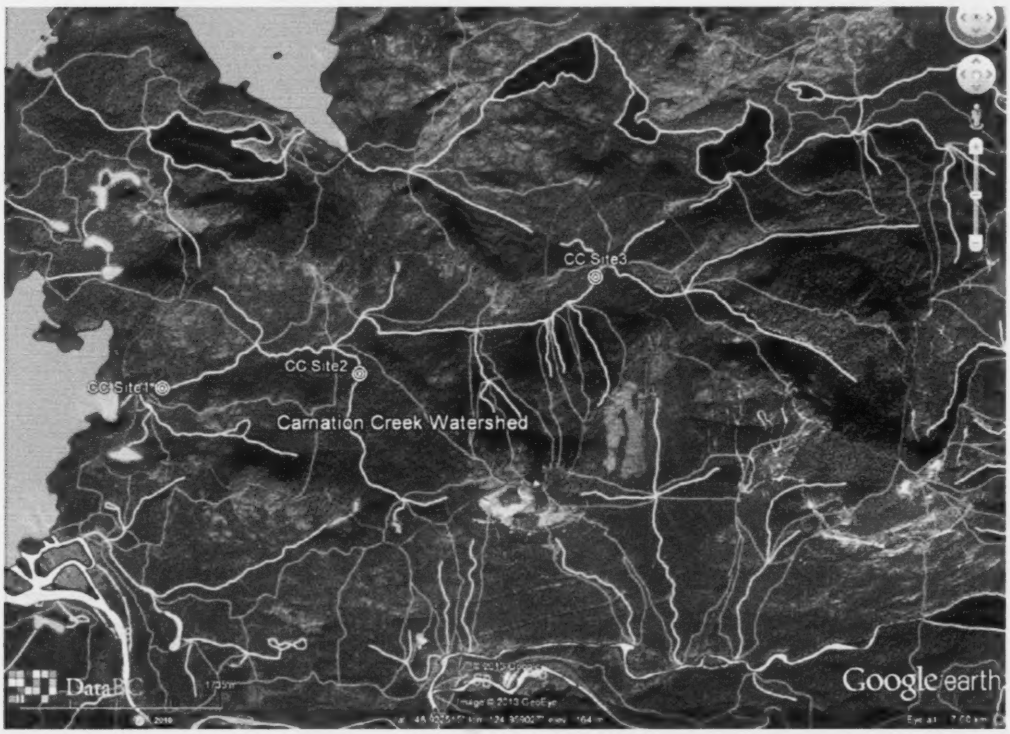

FIGURE 3 *Carnation Creek watershed boundary (red line) and component drainages.*

lakes and wetlands in the watershed, and each polygon was saved specifically in *My Places*. Once completed, the saved polygons were displayed, along with the topographic (elevation) contour lines, and the watershed boundary was checked for accuracy. The final boundary should always be verified because sometimes, based on the contour information, adjustments will be required.

Calculate watershed, lake, and wetland areas The watershed, lake, and wetland polygons that were created were then exported from Google Earth in KML format. There are several online tools for automatically calculating the area of a polygon (e.g., KML Tools Project, Earth Point Tools for Google Earth). The respective KML files were uploaded to one of the previously mentioned websites to calculate Carnation Creek's area as 11.3 km^2, its lake area as 1.8 ha, and its wetland area as 2.4 ha.

Plotting other information Three potential monitoring sites (Sites 1, 2, and 3) were located by using the place markers (push pin icon) in Google Earth. *Line/Font Style* settings were modified by right clicking *properties*, as described in Section 2.2 Map Creation. The number of stream crossings per tributary was determined for the entire watershed by counting where roads and stream lines crossed. Figure 4 shows that there are at least 16 stream crossings across tributaries and the mainstem in the Carnation Creek watershed. The length of the mainstem (7.8 km) was measured using the Google Earth ruler tool. The combined lengths of the tributaries (10.58 km) were also measured using this tool. It was observed that not all roads (including temporary access roads) seem to be displayed in the *BCGov Base Mapping WMS* coverage (more on this point later in the air photos section). Therefore, the *Forest Road Sections FTEN* and *Forest Road Segments FTEN* layers in the *BCGov Licences and Permits WMS* folder were also used. Roads that were highlighted in these combined layers measured 23.5 km. Experience in using B.C. Government Web mapping layers in Google Earth has shown that not all roads are highlighted when the above mentioned layers/techniques are used. Therefore, the tally of steam crossings in the watershed and the length of roads were viewed as preliminary estimates. The Google Earth ruler tool was also used to measure other watershed properties. The watershed is approximately 7 km long and its maximum width is 2 km. The creek drains roughly northeast to southwest (Figure 4).

To obtain elevation, the topographic (elevation) contour layer in the *Base Mapping WMS, Base Mapping 1:20,000 folder* was used and the elevations were read directly from the contours (rather than using the mouseover pointer). This process indicated that Carnation Creek ranges from 0 to 855 m elevation. At this point, much of the information in the watershed physical description table was available (Table 2).

FIGURE 4 *Carnation Creek watershed known stream crossings. Red line denotes watershed boundary, yellow lines are roads, blue lines are streams.*

TABLE 2 *Watershed physical description table template*

Watershed size (km²)	11.3	**Length of watershed (km)**	7
Location	West coast Vancouver Island	**Width of watershed (km)**	2
Relief (m)	0–855	**Number of stream crossings**	16
Biogeoclimatic zone(s)	CWH	**Length of mainstem (km)**	7.80
Land uses (%)	Research, forestry	**Length of tributaries (km)**	10.58
Land ownership		**Total length of all channels (km)**	18.38
TFL/TSA		**Length of roads (km)**	
Forest District/Region		**Lake area (ha)**	1.6
Total disturbed area (km²)		**Wetland area (ha)**	2.5
		Glacier area (ha)	None visible

2.3 Air Photos / Satellite Photos

Air photo centres and flight lines from different time periods were located using the *BCGov Airphoto System* folder for the time period of interest (Figure 5). Unfortunately, there were no air photos for Carnation Creek available in iMapBC or Google Earth that were of an appropriate scale to identify changes in the creek's stream channels (i.e., they were not detailed enough because the creek is small). Ordering air photos from a couple of different time periods would be required for this purpose. Historic air photos can now

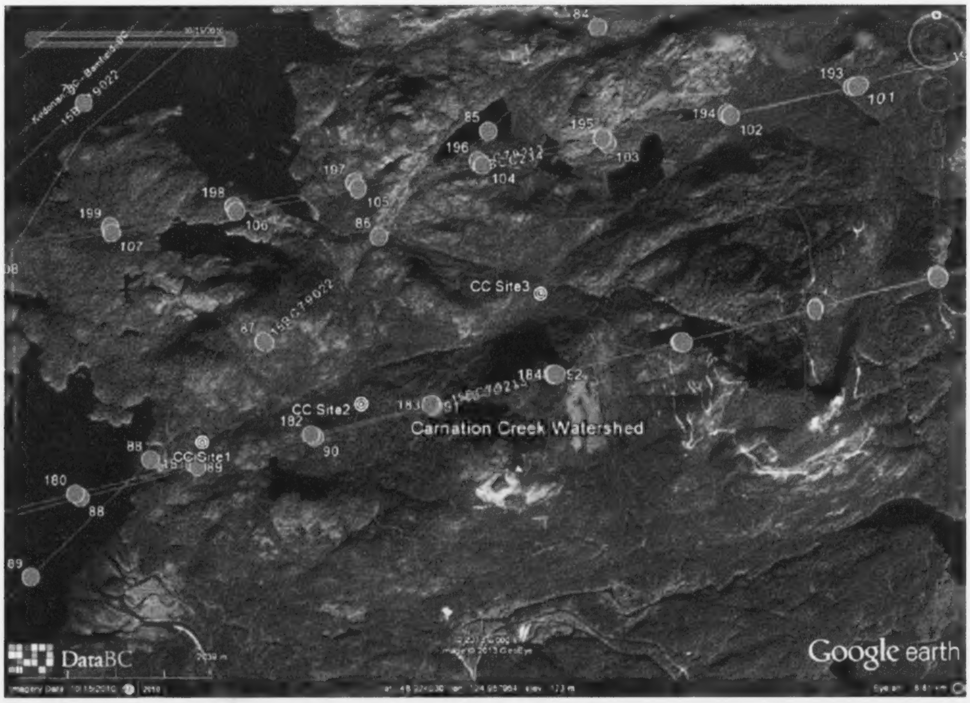

FIGURE 5 *Example of air photo flight lines available for Carnation Creek.*

be ordered through www.basemaps.gov.bc.ca/ or the University of British Columbia Air Photo Library: www.geog.ubc.ca/resources/gic/air_photo.html.

Remotely sensed data, maps, and other information can be obtained through the Natural Resources Canada *GeoGratis website*. A limited amount of remotely sensed data for British Columbia is available in Google Earth. This information can be accessed by going to *BCGov Imagery WMS*, clicking *Provincial Mosaics* subfolder, and then selecting the appropriate coverage. For Carnation Creek, the stock photos on Google Earth, which were taken within the last 2–3 years, and one layer under *BCGov Imagery WMS* called "*Fused SPOT-5/Landsat-5 2004–2006 Black and White (15m)*," were the only time-dated images available. Even though the stated time period was likely incorrect (P. Tschaplinski, pers. comm., Feb. 14, 2013), the images showed a big change in the forest cover in the watershed over time. Hence, although a sense of the overall level of disturbance can be obtained, the timing of such disturbances may not be apparent when using these desktop approaches. The images also showed that the roads that were predefined in Google Earth underestimated the actual length of roads (both historical and currently maintained) in the upper watershed. To address this, the *Transportation* layer and *BCGovLicences and Permits WMS* layers were turned on, and the omitted roads and skid trails were added to the cumulative tally (4.84 km of additional roads). In this example, it may be useful to flick the older image layer on and off to contrast changes in features such as land cover, lake areas, and wetland areas over the two time periods. This indicated that these features have remained fairly constant; only minor changes have occurred between the two

time periods (Figure 6). No other stream crossings were located using this additional procedure.

The polygon measuring process was used to measure the forest cover polygons that remained unaltered and it was determined that 4.6 km² of old growth was undisturbed. When this area was subtracted from the watershed area and divided by the total watershed area (11.3 km²), the calculated disturbance level was 59.2%. The actual total disturbance level is 62% (P. Tschaplinski, pers. comm., Feb. 2013), which is very close to the estimate derived from Google Earth information. The above information was subsequently added to Table 2.

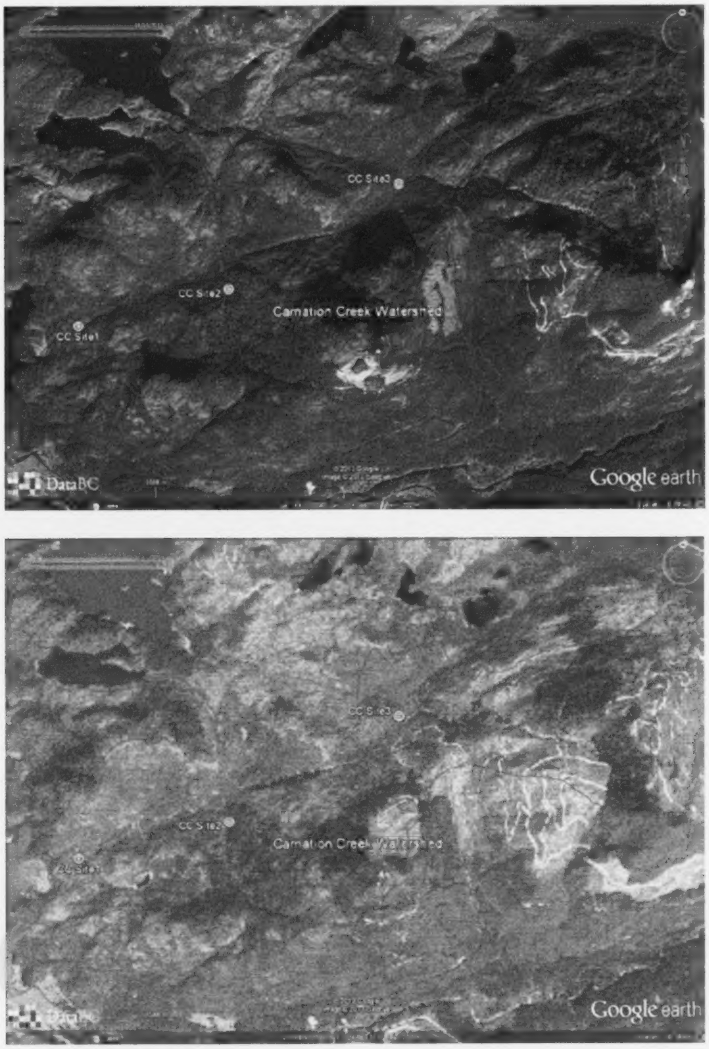

FIGURE 6 *Historic and current imagery for Carnation Creek (undated). Red line denotes watershed boundary.*

2.4 Climate Description

A search of climate data collected near Carnation Creek was conducted using the PCIC Provincial Climate Data Set (PCDS) portal. This indicated there were at least three weather stations in the Carnation Creek watershed that had historical climate data. These data were accessible by registering with the PCDS website.

A search of the Environment Canada National Climate Data and Information Archive revealed that daily, monthly, and almanac data were available for a station called *Carnation Creek CDF*. Canadian climate normals from 1971 to 2000 were also available for this station (summarized in Tables 3 and 4). Published annual climate data could also be used to examine the variability in climate variables.

TABLE 3 *Annual and January–June climate normals for Carnation Creek CDF*

Carnation Creek CDF	Annual	Jan.	Feb.	Mar.	Apr.	May	June
Daily average temperature (°C)	9.6	4.4	5.1	6.7	8.5	11.1	13.3
Daily maximum temperature (°C)	13.6	7.4	8.5	10.8	13.0	15.5	17.7
Daily minimum temperature (°C)	5.6	1.4	1.6	2.6	3.9	6.6	9.0
Rainfall (mm)	2854.0	375.9	373.5	332.0	188.1	140.6	101.2
Snowfall (cm)	21.6	4.1	8.4	1.0	0.4	0	0
Precipitation (mm)	2875.6	380.0	381.9	333.0	188.5	140.6	101.2

TABLE 4 *July–December climate normals for Carnation Creek CDF*

Carnation Creek CDF	July	Aug.	Sept.	Oct.	Nov.	Dec.
Daily average temperature (°C)	15.1	15.5	14.2	10.6	6.3	4.3
Daily maximum temperature (°C)	19.5	20.0	19.0	14.7	9.4	7.2
Daily minimum temperature (°C)	10.6	11.1	9.4	6.3	3.1	1.4
Rainfall (mm)	63.7	68.6	115.5	283.1	416.2	395.4
Snowfall (cm)	0	0	0	0.1	1.3	6.6
Precipitation (mm)	63.7	68.6	115.5	283.2	417.5	402.0

If no weather stations had been available, the Google Map version of Climate WNA could have been used to generate modelled, watershed-specific climate data. Climate WNA could also have been used to examine the annual variability in climate variables. Both lower- and upper-elevation locations could be selected to compare the potential effects of elevation on climatic variables across a number of years. In this template example, Climate WNA was used to investigate potential future climatic changes. Three climate-change scenarios were run using this tool at two different elevations to compare different potential futures (Tables 5 and 6) against the 1971–2000 baseline period.

Much information about the hydrologic regime of a watershed can be derived from climate data. The modelled data produced by Climate WNA were fairly close to the normals and annual data obtained from Environment Canada. The modelled mean annual temperature produced by Climate WNA (10.1°C, Table 5) was very close to the measured mean annual temperature

TABLE 5 *Example Climate Western North America output for Carnation Creek at the 3-m contour*

Carnation Creek at 3-m contour	MAT	MAP	PAS	PPT_ wt	PPT_ sp	PPT_ sm	PPT_ at	PAS_ wt	PAS_ sp	PAS_ sm	PAS_ at
Baseline (current) 1971–2000	10.1	2998	69	1176	682	237	903	41	9	0	19
HadGEM A1B run 1 (hot/dry)	14.7	3267	14	1262	714	121	1170	9	0	0	5
CGCM3 A2 run 4 (warm/very wet)	13.2	3598	20	1382	844	212	1161	12	2	0	6
HadCM3 B1 run 1 (cool/wet)	12.1	3081	52	1209	686	152	1033	39	3	0	10

MAT: mean annual temperature (°C); MAP: mean annual precipitation (mm); PAS: precipitation as snow (mm); PPT_wt: winter precipitation (mm); PPT_sp: spring precipitation (mm); PPT_sm: summer precipitation (mm); PPT_at: autumn precipitation (mm); PAS_wt: winter snow (mm); PAS_sp: spring snow (mm); PAS_sm: summer snow (mm); PAS_at: autumn snow (mm)

TABLE 6 *Example Climate Western North America output for Carnation Creek at the 680-m contour*

Carnation Creek at 680-m contour	MAT	MAP	PAS	PPT_ wt	PPT_ sp	PPT_ sm	PPT_ at	PAS_ wt	PAS_ sp	PAS_ sm	PAS_ at
Baseline (current) 1971–2000	8.0	3924	271	1527	904	309	1184	156	46	0	69
HadGEM A1B run 1 (hot/dry)	12.6	4284	57	1640	944	157	1543	37	3	0	17
CGCM3 A2 run 4 (warm/very wet)	11.1	4709	82	1794	1115	274	1526	50	10	0	22
HadCM3 B1 run 1 (cool/wet)	10.0	4037	202	1573	908	198	1358	149	17	0	36

MAT: mean annual temperature (°C); MAP: mean annual precipitation (mm); PAS: precipitation as snow (mm); PPT_wt: winter precipitation (mm); PPT_sp: spring precipitation (mm); PPT_sm: summer precipitation (mm); PPT_at: autumn precipitation (mm); PAS_wt: winter snow (mm); PAS_sp: spring snow (mm); PAS_sm: summer snow (mm); PAS_at: autumn snow (mm)

(9.6°C, Table 3). Similarly, the modelled mean annual precipitation produced by Climate WNA (2998 mm, Table 5) was very close to the measured mean annual precipitation (2875.6 mm, Table 3). This suggested that the modelled climate variables were representative. However, we observed a great deal of variability in the measured mean annual precipitation values among a few years that were examined. For example, the lowest annual precipitation was 1866 mm (1985), while the highest recorded was almost double that value at 3573 mm (1974). This indicated that annual precipitation at Carnation Creek is quite variable between dry and wet years. The climate information revealed that the dominant component of mean annual precipitation is rain; that is, only 2–7 % falls as snow, on average. The hydrologic regime of Carnation Creek is therefore rain-dominated and strongly coupled to seasonal weather patterns. The climate data also revealed that the biggest accumulations of snow occur during the winter (January/February/March) while most of the yearly precipitation falls from September to March. This is the period during which the highest peak discharges would likely occur. Low flows would likely occur in the late summer, based on the climate data.

The modelled data can show how climate variables change in relation to elevation. The modelled mean annual precipitation data showed that precipitation increased with elevation; for Carnation Creek, there was approximately

a 1000 mm difference from the bottom (3 m) to the top (680 m) of the watershed (2998 vs. 3924 mm, Tables 5 and 6). Because modelled data were used, the gradient was treated as a preliminary estimate for characterizing precipitation trends in the watershed.

Climate parameters were examined for potential changes in the future (Tables 5 and 6). Running an assortment of emissions scenarios for the 2050s indicated that mean annual temperature could increase by almost 4.5°C near the ocean (from 10.1 to 12.1–14.7°C). Projected mean annual temperature changes in the upper watershed were similar (from 8 to 10–12.6°C) at 680 m elevation. Increased mean annual temperatures may have an effect on streamflow, vegetation, water quality, and, ultimately, aquatic processes. Across all three modelled scenarios, summer precipitation amounts were forecast to decrease in the future. Summer precipitation was forecast to decrease from 237 to 121–212 mm near the estuary and from 309 to 157–274 mm in the upper watershed. A decrease in summer precipitation would likely exacerbate existing low summer flow conditions, and thereby influence water quality parameters (e.g., stream temperature) and aquatic life in Carnation Creek.

2.5 General Hydrology and Drainage Characteristics

Information on a watershed's hydrologic regime can be gained by interpreting climate data, using information in the B.C. Government layers in Google Earth, and analyzing hydrometric data. Thus, hydrometric data can be transferred from neighbouring watersheds if no local watershed data are available. The depth of hydrology and hydrometric analysis required is driven by the monitoring/research project objectives. The following example analyses provide a range of options for describing general hydrology and drainage characteristics in a watershed.

A hydrological characterization can be initiated by obtaining discharge data from the nearest WSC station or closest alternative station. Two WSC stations were identified within the Carnation Creek watershed (see *BCGov Freshwater and Marine WMS* and subfolder *BC Hydrometric Stations*). Historical data for these stations were obtained from www.wateroffice.ec.gc.ca/index_e.html. The Google Map search on this site identified one active station (Carnation Creek at the mouth – 08HB048) and one discontinued station (Carnation Creek at 150-m contour 08HB069) with 39 and 21 years of observations on record, respectively. The lower-elevation (active) station was used to characterize the hydrology of the watershed because it had the longest record and represented all three proposed monitoring sites.

The following summaries for *Carnation Creek at the mouth – 08HB048* were obtained (Tables 7 and 8) from the WSC B.C. River Levels website.

TABLE 7 *Mean, maximum, and minimum monthly and annual discharge (m^3/s) data for Carnation Creek at the mouth – 08HB048. Source: Water Survey of Canada.*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean (m^3/s)	1.610	1.270	1.080	0.691	0.377	0.229	0.129	0.131	0.209	0.841	1.710	1.530	0.813
Max (m^3/s)	3.360	3.040	2.410	1.450	0.948	0.772	0.615	1.340	0.841	2.310	4.040	2.610	1.130
Min (m^3/s)	0.184	0.184	0.279	0.070	0.062	0.038	0.013	0.007	0.010[a]	0.025	0.469	0.492[a]	0.430

a Occurs more than once.

TABLE 8 *Maximum and minimum instantaneous and daily discharge data (m^3/s) for Carnation Creek at the mouth – 08HB048, 1977–2011. Source: Water Survey of Canada.*

Year	Maximum instantaneous discharge (m^3/s)	Minimum instantaneous discharge (m^3/s)	Maximum daily discharge (m^3/s)	Minimum daily discharge (m^3/s)
1977	34.8 at 04:06 PST[a] on Feb. 12	–	13.1 on Feb. 12	0.034 on Aug. 18
1978	43.9 at 13:46 PST on Nov. 07	–	11.4 on Nov. 07	0.037 on Aug. 01
1979	23.4 at 06:05 PST on Dec. 17	–	13.5 on Dec. 17	0.035 on Aug. 31
1980	43.1 at 05:27 PST on Dec. 26	–	21.6 on Dec. 26	0.067 on Aug. 15
1981	20.9 at 18:24 PST on Oct. 30	–	11.0 on Oct. 31	0.057 on Aug. 23
1982	50.0 at 17:18 PST on Jan. 23	–	13.7 on Jan. 23	0.005 on Sept. 05
1983	36.2 at 12:57 PST on Feb. 11	–	20.0 on Feb. 11	0.013 on Oct. 13
1984	65.1 at 22:37 PST on Jan. 03	–	20.0 on Jan. 04	0.021 on Aug. 26
1985	11.5 at 12:52 PST on Nov. 01	–	4.99 on Nov. 01	0.003 on Aug. 05
1986	49.3 at 17:40 PST on Feb. 23	–	23.2 on Feb. 24	0.013 on Sept. 06
1987	22.0 at 02:22 PST on Nov. 24	–	10.6 on Mar. 04	0.006 on Oct. 24
1988	21.0 at 14:53 PST on Nov. 05	–	9.00 on Nov. 05	0.017 on Aug. 08
1989	46.6 at 21:50 PST on Nov. 09	–	24.7 on Nov. 09	0.019 on Sept. 14
1990	–	–	24.4A on Nov. 10	0.019 on Aug. 11
1991	43.7 at 09:24 PST on Feb. 04	0.01 at 18:01 PST on Oct. 31	16.9 on Feb. 01	0.011 on Oct. 31
1992	27.7 at 19:34 PST on Jan. 29	0.01 at 16:48 PST on Aug. 04	19.0 on Jan. 23	0.013 on Aug. 03
1993	49.1 at 20:56 PST on Jan. 24	0.01 at 21:20 PST on Sept. 26	14.1 on Jan. 24	0.005 on Sept. 26
1994	26.2 at 06:10 PST on Dec. 19	0.00 at 11:06 PST on Sept. 02	14.8 on Dec. 19	0.004 on Aug. 27
1995	44.7 at 15:26 PST on Nov. 28	–	20.7A on Nov. 17	0.011 on July 19
1996	18.0 at 13:55 PST on Nov. 08	0.00 at 07:19 PST on Aug.14	8.23 on Nov. 08	0.004 on Aug. 10
1997	32.2 at 00:05 PST on Jan. 30	–	12.8 on Mar. 18	0.066 on Aug. 01
1998	19.1 at 04:05 PST on Nov. 15	–	11.3 on Jan. 23	0.013 on Sept. 02
1999	24.6 at 10:40 PST on Nov. 09	0.02 at 16:17 PST on Aug. 09	13.1 on Nov. 09	0.019 on Aug. 09
2000	–	0.011 at 14:20 PST on July 21	6.68A on Oct. 17	0.011 on July 21
2001	24.6 at 21:03 PST on Jan. 04	0.03 at 16:00 PST on July 27	9.59 on Dec. 16	0.035 on July 26
2002	29.2 at 14:17 PST on Nov. 19	0.02 at 10:00 PST on Aug. 12	17.9 on Nov. 19	0.017 on Aug. 12
2003	22.3 at 01:31 PST on Oct. 18	0.01 at 12:42 PST on Sept. 03	14.8 on Oct. 18	0.011 on Aug. 29
2004	21.5 at 07:56 PST on Nov. 07	0.02 at 20:31 PST on Aug. 05	14.2 on Nov. 07	0.020 on Aug. 01
2005	23.3 at 09:41 PST on Sept. 29	0.01 at 22:01 PST on Sept. 14	13.5 on Jan. 19	0.013 on Aug. 26
2006	19.7 at 08:16 PST on Nov. 15	0.01 at 21:11 PST on Aug. 15	11.3 on Nov. 15	0.013 on Aug. 23
2007	22.2 at 07:11 PST on Nov. 12	0.03 at 00:21 PST on Sept. 16	12.8 on Oct. 22	0.035 on Sept. 12
2008	14.3 at 02:06 PST on Nov. 08	0.01 at 10:01 PST on July 23	7.81 on Nov. 08	0.014 on July 23
2009	19.2 at 19:46 PST on Jan. 06	0.01 at 10:06 PST on Dec. 14	11.0 on Jan. 07	0.008 on Dec. 12
2010	19.1 at 19:21 PST on Jan. 11	0.01 at 15:26 PST on Aug. 01	11.3 on Dec. 24	0.013 on July 31
2011	19.2 at 06:50 PST on Nov. 27	0.01E at 07:32 PST on Sept. 15	10.2 on Jan. 16	0.016E on Sept. 14

a PST: Pacific Standard Time; A: Partial Day; E: Estimated

Both of the above summaries can be automatically generated for any WSC hydrometric station. However, if a more detailed hydrometric analysis is required or if hydrometric data are not available from WSC, the U.S. Army Corps of Engineers' computer program HEC-SSP can be used to analyze hydrologic data. The daily data files from WSC must be must be formatted specifically for use in HEC-SPP. A number of analyses can be generated using the HEC-SPP software. It is recommended that *Monthly Duration Analysis* be calculated using the daily averaged streamflow data (example output in Table 9).

TABLE 9 *Analysis of monthly discharge (m^3/s) exceedances for Carnation Creek at the mouth – 08HB048*

% of time exceeded	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
99	0.085	0.066	0.097	0.054	0.025	0.019	0.008	0.004	0.007	0.007	0.036	0.031
95	0.113	0.097	0.127	0.087	0.036	0.028	0.014	0.008	0.011	0.017	0.090	0.103
90	0.140	0.128	0.160	0.112	0.053	0.036	0.018	0.013	0.016	0.026	0.142	0.139
85	0.181	0.153	0.195	0.136	0.072	0.046	0.022	0.015	0.019	0.034	0.204	0.185
80	0.224	0.179	0.224	0.164	0.086	0.054	0.025	0.016	0.023	0.049	0.255	0.237
75	0.265	0.209	0.258	0.191	0.096	0.063	0.028	0.018	0.026	0.065	0.320	0.279
70	0.310	0.244	0.296	0.218	0.109	0.071	0.031	0.020	0.030	0.085	0.385	0.342
65	0.366	0.297	0.334	0.255	0.122	0.081	0.035	0.022	0.036	0.117	0.455	0.422
60	0.452	0.352	0.378	0.283	0.136	0.089	0.040	0.024	0.042	0.135	0.542	0.504
55	0.568	0.444	0.441	0.324	0.154	0.099	0.048	0.027	0.051	0.170	0.659	0.595
50	0.696	0.543	0.536	0.365	0.176	0.108	0.055	0.031	0.061	0.221	0.789	0.719
45	0.874	0.659	0.626	0.425	0.197	0.122	0.062	0.037	0.074	0.288	0.973	0.873
40	1.060	0.799	0.732	0.480	0.229	0.135	0.070	0.040	0.085	0.372	1.180	1.040
35	1.290	0.960	0.865	0.549	0.263	0.151	0.080	0.046	0.098	0.481	1.406	1.233
30	1.606	1.158	1.080	0.636	0.309	0.171	0.093	0.060	0.113	0.631	1.737	1.503
25	1.982	1.450	1.272	0.759	0.381	0.200	0.102	0.068	0.138	0.836	2.147	1.890
20	2.516	1.874	1.580	0.948	0.476	0.247	0.117	0.078	0.187	1.230	2.590	2.270
15	3.131	2.330	1.951	1.207	0.638	0.320	0.140	0.095	0.282	1.593	3.140	3.001
10	4.193	3.306	2.531	1.700	0.878	0.476	0.193	0.139	0.443	2.501	4.130	3.972
5	6.220	4.954	3.640	2.579	1.472	0.886	0.383	0.374	0.880	3.820	6.098	5.676
2	9.765	7.270	5.877	3.884	2.517	1.654	0.838	1.075	1.625	6.034	10.518	8.614
1	11.342	9.482	7.644	4.570	3.230	2.321	1.554	2.175	2.407	8.434	13.459	9.768

Calculation of the median value (50% of the observations exceed this value and 50% are below) allows the monthly means and monthly medians to be compared. Large differences between these two statistics generally indicate a lack of normality in the data (e.g., the mean is influenced by infrequent storms more so than the median). In such instances, the median monthly flow can better describe non-normal flow data. For example, in August, 50%

of the historic observations were at 0.031 m³/s, whereas the mean inflated the measure of water availability to 0.131 m³/s. This is important to know if allocation or management decisions are to be made during this time period. Using the table previously obtained from WSC, median monthly flows were added (Table 10). From these data, a simple graph was generated to display the monthly patterns of runoff at Carnation Creek (Figure 7). The shape of this graph and the timing of the peak runoff describe the general hydrologic regime.

TABLE 10 *Median, mean, mean maximum, and mean minimum monthly and annual discharge (m³/s) at Carnation Creek at the mouth – 08HB048*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Median (m³/s)	0.696	0.543	0.536	0.365	0.176	0.108	0.055	0.031	0.061	0.221	0.789	0.719	0.232
Mean (m³/s)	1.610	1.270	1.080	0.691	0.377	0.229	0.129	0.131	0.209	0.841	1.710	1.530	0.813
Max. (m³/s)	3.360	3.040	2.410	1.450	0.948	0.772	0.615	1.340	0.841	2.310	4.040	2.610	
Min. (m³/s)	0.184	0.184	0.279	0.070	0.062	0.038	0.013	0.007	0.010[a]	0.025	0.469	0.492[a]	

a Occurs more than once.

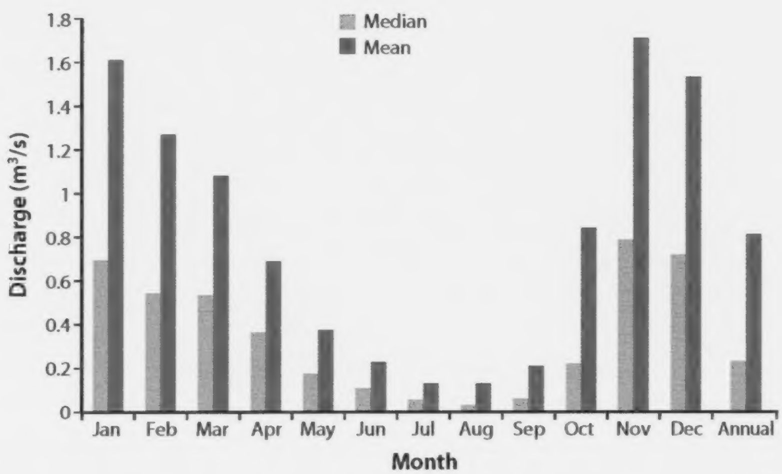

FIGURE 7 *Mean and median monthly/annual discharge (m³/s) data for Carnation Creek at the mouth – 08HB048.*

Analysis of wet vs. dry years was conducted by plotting the mean annual discharge across the years and using the long-term mean annual discharge level (0.813 m³/s, Table 10) as the point of reference (Figure 8). Annual median and monthly median values can also be used for this type of analysis.

If the data record is sufficiently variable and long (e.g., >10 years, preferably >20 years), a first approximation of flood frequency curves can be generated using HEC-SSP. The example provided in Figure 9 is for instantaneous maximum discharges vs. return period and probability of occurrence.

HEC-SSP was also used to analyze historic low flows of 1-, 3-, or 7-day occurrences (Table 11).

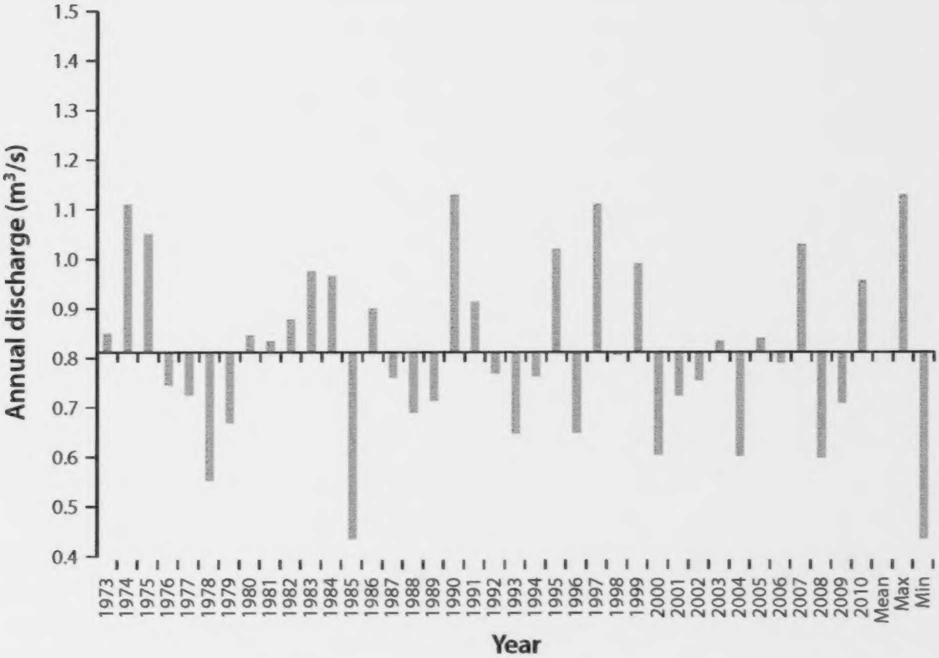

FIGURE 8 *Analysis of wet vs. dry years based on the mean annual discharge (m^3/s) for Carnation Creek at the mouth – 08HB048, from 1973 to 2010.*

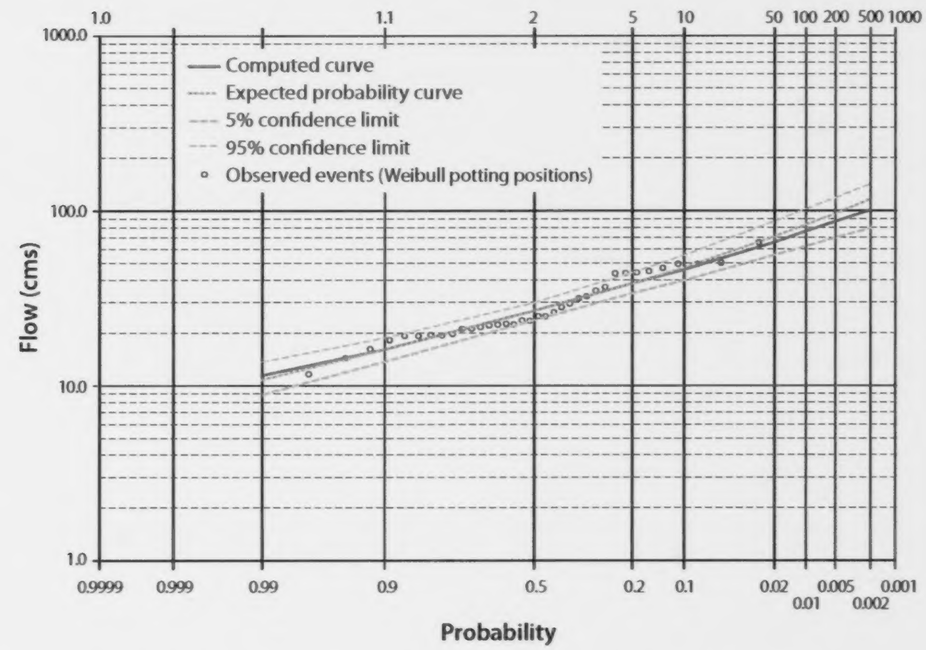

FIGURE 9 *Instantaneous maximum discharges (1 cms = 1 m^3/s) vs. return period/probability for Carnation Creek at the mouth – 08HB048.*

TABLE 11 *Analysis of Carnation Creek low flows (m^3/s) for 1-, 3-, and 7-day occurrences, 1976–2010*

	1-day		3-day		7-day	
Year	Date	Discharge (m^3/s)	Date	Discharge (m^3/s)	Date	Discharge (m^3/s)
1976	08/10/1976	0.042	08/12/1976	0.042	08/12/1976	0.045
1977	08/18/1977	0.034	08/20/1977	0.034	08/22/1977	0.035
1978	08/01/1978	0.037	08/03/1978	0.037	08/07/1978	0.037
1979	08/31/1979	0.035	08/31/1979	0.036	09/01/1979	0.037
1980	08/15/1980	0.067	08/16/1980	0.067	08/16/1980	0.069
1981	08/23/1981	0.057	08/25/1981	0.058	08/27/1981	0.060
1982	09/05/1982	0.005	09/06/1982	0.006	09/06/1982	0.006
1983	10/13/1983	0.013	10/14/1983	0.013	10/15/1983	0.015
1984	08/26/1984	0.021	09/03/1984	0.022	09/01/1984	0.024
1985	08/05/1985	0.003	08/06/1985	0.003	08/06/1985	0.004
1986	09/06/1986	0.013	09/07/1986	0.014	09/10/1986	0.015
1987	10/24/1987	0.006	10/28/1987	0.006	10/28/1987	0.007
1988	08/08/1988	0.017	08/14/1988	0.017	08/14/1988	0.018
1989	09/14/1989	0.019	09/15/1989	0.020	09/16/1989	0.022
1990	08/11/1990	0.019	08/12/1990	0.019	08/15/1990	0.020
1991	10/31/1991	0.011	11/01/1991	0.012	11/03/1991	0.013
1992	08/03/1992	0.013	08/05/1992	0.013	08/05/1992	0.014
1993	09/26/1993	0.005	09/26/1993	0.006	10/11/1993	0.006
1994	08/27/1994	0.004	08/29/1994	0.004	09/02/1994	0.004
1995	07/19/1995	0.011	07/24/1995	0.012	07/24/1995	0.013
1996	08/10/1996	0.004	08/12/1996	0.004	08/16/1996	0.004
1997	08/01/1997	0.066	08/19/1997	0.067	08/19/1997	0.068
1998	09/02/1998	0.013	09/03/1998	0.013	09/06/1998	0.015
1999	08/09/1999	0.019	08/10/1999	0.019	08/11/1999	0.020
2000	07/21/2000	0.011	07/22/2000	0.011	07/25/2000	0.012
2001	07/26/2001	0.035	07/27/2001	0.036	07/27/2001	0.038
2002	08/12/2002	0.017	08/13/2002	0.018	08/14/2002	0.019
2003	08/29/2003	0.011	08/31/2003	0.011	09/03/2003	0.012
2004	08/01/2004	0.020	08/03/2004	0.020	08/06/2004	0.020
2005	08/26/2005	0.013	08/27/2005	0.014	08/27/2005	0.016
2006	08/23/2006	0.013	08/23/2006	0.014	08/23/2006	0.014
2007	09/12/2007	0.035	09/14/2007	0.035	09/16/2007	0.037
2008	07/23/2008	0.014	07/25/2008	0.016	07/28/2008	0.018
2009	12/12/2009	0.008	12/14/2009	0.008	08/08/2009	0.010
2010	07/31/2010	0.013	08/02/2010	0.013	08/05/2010	0.013

Based on this analysis, graphs were plotted in HEC-SSP that related return period/probability of flows (Figure 10).

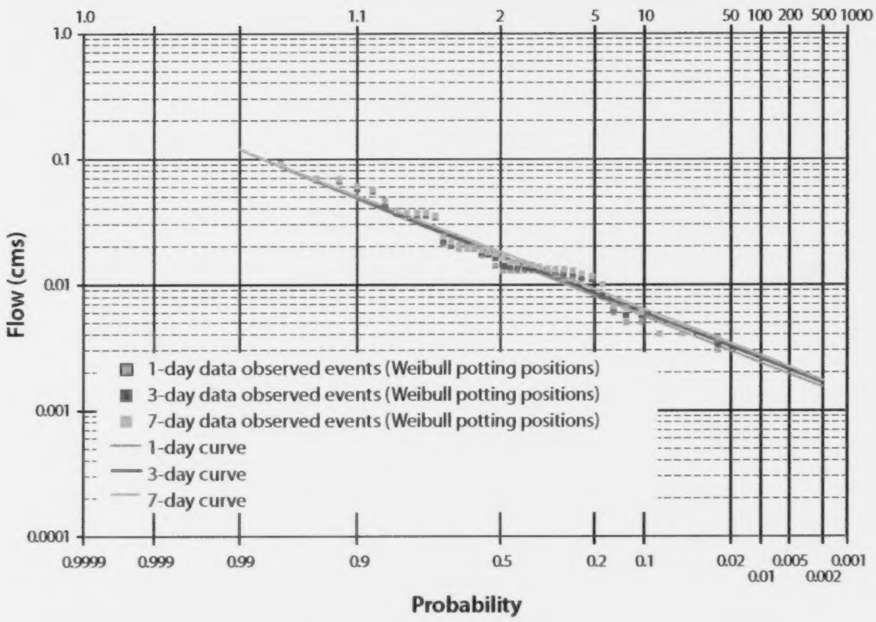

FIGURE 10 *Example low-flow frequency analysis for Carnation Creek at the mouth – 08HB048 (1 cms = 1 m³/s).*

The analysis of the available climate and discharge data was used to answer the list of template questions.

Is the water system regulated or natural? Are any diversions present?

The watershed appears to be a natural system with no points of diversion highlighted (see *BCGov Freshwater and Marine* WMS, subfolder *Points of Diversion*). There are points of diversion outside the watershed but none within. These locations would have been flagged for field investigation if buildings or other infrastructure had been present in the air photos.

What is the expected hydrologic regime (rain, snow, hybrid, glacial) of the area?

Based on the climate data and hydrometric data analysis, Carnation Creek is a rain-dominated regime. In the winter, there may be periods of snow accumulation and subsequent melt that increase the magnitude of winter storm events. There are no glaciers in the watershed, and the snow accumulation percentage of mean annual precipitation is too low to cause the watershed to have rain-snow hybrid characteristics. Examination of the mean/median monthly discharge graph (Figure 7) is often the best way to determine a watershed's hydrologic regime (i.e., when the discharge is greatest). In the Carnation Creek watershed, there is no spring/summer melt or added amounts due to glaciers in the late summer. Figure 7 is a classic example of a rainfall-dominated hydrologic regime.

In terms of water storage and release components, what is the role of wetlands, lakes, dams/diversions, glaciers, preferential flow, and groundwater in shaping daily and/or seasonal discharge?

Information from Google Earth indicated that there is one small wetland and one small lake in the watershed that drain into Carnation Creek immediately at the creek's confluence with its estuary. This water is not captured by the WSC gauge; therefore, these features will have no effect on the flow characteristics of the proposed monitoring sites. It is unknown to what extent groundwater contributions or preferential flow through the soil influence discharge timing and magnitude in this watershed. These questions were flagged for further study.

Is runoff rapid or a prolonged event? Does runoff occur immediately after a storm or is it delayed? What is the primary hydrologic driver (snow, rain, groundwater, glaciers, or convective storms)?

The primary climatic hydrologic driver in the watershed is rain. Runoff in Carnation Creek typically occurs rapidly (flashy) in response to rain and tends to drop off abruptly upon the cessation of precipitation. The general time of concentration can be determined by comparing flows/weather data and timing of these events. For example, real-time weather for this area was available from www.islandweather.ca/station.php?id=161. The precipitation peak and the hydrograph peak have a similar shape (the streamflow peak is delayed) in the winter, which is within the period of maximum flows (Figure 11). Therefore, it could be concluded that discharge mostly increases with every storm and the peak is dependent on the amount and intensity of precipitation.

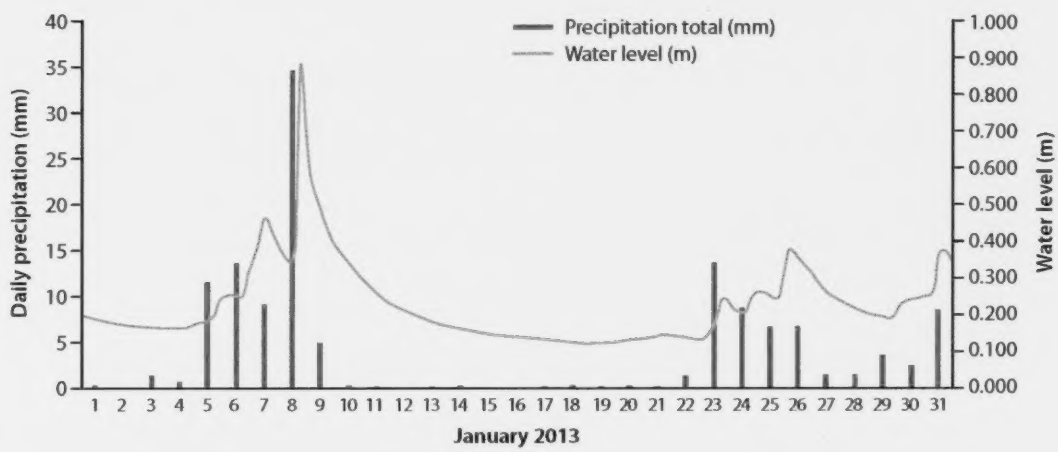

FIGURE 11 *Daily precipitation (mm) at Bamfield Marine Station vs. water levels (m) at Carnation Creek, January 1–31, 2013.*

What is the seasonality of flow? Do low flows occur only in specific seasons or at any time during the year?

Based on the hydrologic data, mean annual discharge is 0.813 m^3/s (Table 10). The highest mean/median monthly flows occur in November through January, while the lowest mean/median monthly flows occur in July and August (Figure 7). This confirmed the initial assumptions about the hydrologic regime based on the Climate WNA modelled data and how runoff is strongly coupled to weather. The data on daily maximums/minimums and instantaneous discharges showed that streamflow peaks occur most often in November and lowest flows of the year occur most often in the summer. However, very low flows have also occurred in October and December. This flagged a need to look further at exceedance probabilities in the daily data in order to accurately characterize the system. The exceedance probabilities tables generated in HEC-SPP were used to examine the "usual" flow regimes on a monthly basis (Table 9). The median monthly flow statistics were used to determine the volume of water in the system (not influenced by extremes). HEC-SSP also produced other low-flow information (Table 12). The 7-day, 5-year low (7Q5) was calculated as 0.009 m^3/s (9 L/s), and the 7-day, 20-year (7Q20) low was 0.005 m^3/s (5 L/s). The all-time lowest recorded at Carnation Creek was close to 0.003 m^3/s (3 L/s).

TABLE 12 *Low-flow frequency analysis results for Carnation Creek at the mouth – 08HB048*

Return period (years)	Yearly probability of occurrence (%)	1-day (m^3/s)	3-day (m^3/s)	7-day (m^3/s)
1.25	80	0.034	0.034	0.036
2	50	0.017	0.017	0.018
5	20	0.008	0.009	0.009
10	10	0.006	0.006	0.006
20	5	0.004	0.005	0.005
50	2	0.003	0.003	0.003
100	1	0.002	0.003	0.003
200	0.5	0.002	0.002	0.002

Does streamflow ever become intermittent along the channel profile? Have zero-flow conditions been measured in the watershed?

There were few instantaneous zero flows on record. It is unknown, however, at this stage, if flows are intermittent along the entire channel profile or just along certain reaches.

Are drainage diversions, roads, ditches or other or impervious surfaces affecting runoff patterns and timing?

There are more than 28 km of roads with impermeable surfaces throughout the watershed. This is 10 km more than the total stream channel network. It is entirely possible that portions of the road network intercept flow through the soils and down the mountain slopes, and redirect it via ditch and road flow into a natural surface drainage. This potential redirection has the ability to accelerate the responsiveness of the watershed to precipitation inputs.

Is information on groundwater/surface water interactions available (e.g., observation wells or water level trends; see www.env.gov.bc.ca/wsd/data_searches/wells/index.html)?

A search provided no results.

Is bedrock geology influencing discharge (e.g., sinking or losing streams)?

Information obtained from iMapBC indicated that the watershed geology is composed of granodioritic intrusive rocks (Island Plutonic group) and alkaline volcanic rocks of the Bonanza Group. There is no mapped karst within the watershed. It is not possible to determine the extent to which geology influences flows in Carnation Creek from this office-based exercise.

Do processes involving ice (e.g., river ice, glaciers, and permafrost) in the watershed affect water quality/quantity parameters?

Not applicable to this watershed.

2.6 Sediment, Stream Channels, and Sediment Yield Potential

Many of the sediment/stream channel questions would be best answered by conducting an on-the-ground site visit to the watershed. Obtaining information from office-based information sources prior to any field visit can help focus field reconnaissance.

Have there been any recent extreme floods? If not, how long ago was the last major flood? Is there evidence of past/recent landslides connected to streams in the watershed? Have there been any recent large mass movement events in the watershed? Is there any obvious evidence of past/recent landslides connected to streams?

The first two questions are often best answered through on-site investigations and/or by accessing historical records (if kept). There is no single, comprehensive database of historical mass movement (landslide) occurrences for British Columbia because reporting and historical records vary between the natural resource regions. However, limited information on the spatial occurrence of recent landslides and other forest health issues can be obtained from www.for.gov.bc.ca/hfp/health/overview/overview.htm. This website features yearly updates of forest health conditions (i.e., insects, diseases, and abiotic influences, such as landslides). For Carnation Creek, no mass movements have been mapped in the most recent forest health surveys.

In the example, no discernible landslides are shown in the remotely sensed images on Google Earth. However, this does not necessarily mean that no landslides have occurred (in fact, many landslides have occurred in Carnation Creek). The ability to detect mass movements (landslides) is a function of the date of the image and the width/length of the landslide relative to the resolution of the imagery. The Google Earth images for Carnation Creek are not of a high enough resolution that an observer untrained in identifying re-vegetated landslide scars could easily determine vegetation cover differences. The office-based analysis using Google Earth therefore does not conclusively detect the presence/absence of historical and recent landslides in this example.

Identification of mass movements may best be performed by using air photos from a few different time periods and by conducting on-site investigations. For example, in Figure 12, the lower landslide in the image shows that sediment likely was deposited into the stream channel. Features such as these would indicate the existence of mass movements and should force consideration of the potential effects of such events, even if they occurred 20–30 years prior.

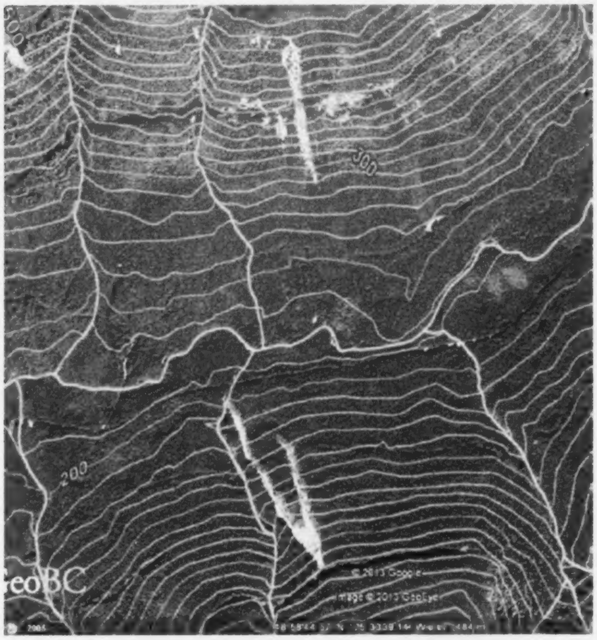

FIGURE 12 *Example of landslide scars. Image obtained from Google Earth.*

Are slopes or existing landslides directly connected to the water body of interest?

Google Earth images show several steep gullies/tributaries that are directly connected to the mainstem channel of Carnation Creek. Information on the percent slope and a longitudinal profile can be developed by measuring along

the mapped stream channel and marking off where elevation contours intersect the channel (e.g., 2460 m from the point of commencement, crossed 20-m contour). This information is recorded in a table of x/y pairs (contour elevation/distance from point of commencement). The distance plotted against the contour elevation shows the steepness of the mainstem and the tributaries (Figure 13). Approximate slope percentages (%) can be calculated from the tabular data (rise/run · 100). For example, C-trib has an average slope of approximately 16%, whereas trib#1 is approximately 48%.

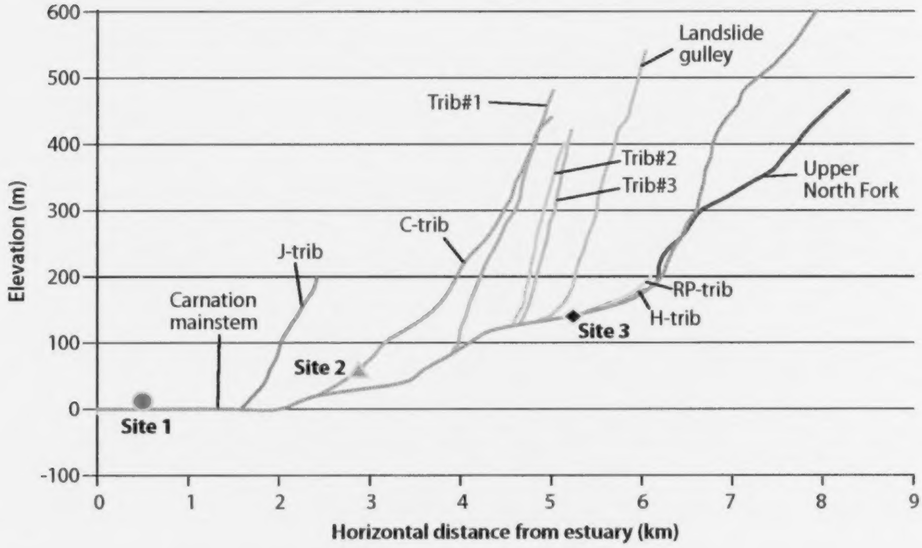

FIGURE 13 *Longitudinal channel profile for Carnation Creek created from Google Earth.*

Thus, there are a number of steep channels and gullies directly connected to the mainstem of Carnation Creek and the likelihood of mass movements from hillslopes connected to the mainstem is high.

Does your watershed have the following? How might these influence the timing and fate of sediment input?

- active fans/active fluvial units, including disturbances
- stream crossings adjacent to erodible materials
- landslide-prone terrain (gullies, gentle over steep, steep or unstable terrain)
- easily erodible soils (e.g., fine lacustrine deposits)
- historic channel widening/alteration of riparian areas
- prominent sources of surface eroded sediment (roads, fine-grained soils)
- chronic, within-channel sediment sources

The map shows several places where the tributaries and gullies join the mainstem (and lose confinement), which are possible fan locations. Google Earth analyses do not provide enough information to determine activity levels/history and possible sediment yield hazards to Carnation Creek. A site

visit is thus required to supplement the information gathered through the desktop exercise.

It was previously noted that there are 16 stream crossings on 28 km of roads. These are easily flagged as sites for investigating potential fine sediment yield production from roads or drainage diversions. With respect to the proposed monitoring sites, there are two stream crossings above Site 3, no stream crossings or roads will affect Site 2, and 13 out of 16 stream crossings could affect measurements at Site 1. Site 2 is likely the best location as a background site, given the stability in forest cover and absence of upstream influence of road/stream crossings. Historic channel widening has probably occurred, given the level of past disturbance.

Does the stream channel show signs of high sediment loading or instability?

This investigative measure is best left to the site inspection examining above and below the proposed monitoring locations. The presence of disturbance tree species, such as deciduous trees (e.g., red alder), or different age classes of vegetation are features to look for during any field investigation.

Qualitatively, does the watershed have a high or low sediment potential?

It appears that the morphology of Carnation Creek is suitable for transporting sediment from the hillslopes directly into the stream channel. There are a number of very steep tributaries and gullies in the upper mainstem that could act as pathways. The proposed location of the three monitoring sites shows that Site 3 and Site 2 have the least amount of exposure to sediment yield potential, while Site 1 has the greatest exposure. Site 2 appears to be the best location as a background control, and Site 1 is perhaps the best if the project needs to determine a cumulative disturbance response. The tributaries above Site 3 are not as steep as downstream, yet the elevation of the watershed is the highest above this proposed monitoring point. This type of analysis does not actually determine the sediment yield potential; rather, it documents the potential exposure of the proposed monitoring sites to sediment-prone features.

2.7 Land Uses and Natural Disturbances

The natural disturbance drivers in the watershed (e.g., forest health, climate change, terrain) that could affect discharge and/or water quality should be described. What is the approximate footprint and location of each in the watershed? The major land uses in the watershed (e.g., forestry, agriculture, range, recreation, parks, protected areas, mining, oil and gas, urban, power/run-of-river projects) should also be described. What is the approximate footprint and location of each in the watershed (e.g., clearcuts are distributed over 50% of the watershed above 500 m)?

Based on the Google Earth analysis, forestry is the primary land use in the watershed. There is no obvious infrastructure aside from a solitary building near the estuary. Contact with the owner is flagged for further investigation. Investigation of land ownership will help determine the major land uses. A search of the provincial forest health website www.for.gov.bc.ca/hfp/health/overview/overview.htm revealed no major forest health issues (insects, disease, or abiotic issues).

Using Google Earth, the following information is gathered for the completion of the descriptive table.

BCGov Forests Grasslands and Wetlands WMS

- Carnation Creek is in the CWH zone (see *BEC analysis All*).

BCGov Administrative Boundaries WMS

- The *First Nations Treaty* layer showed that a portion of lower Carnation Creek is treaty settlement lands for the Huu-ay-aht First Nations (Figure 14).
- The *Indian Reserves* layer showed a small portion of the lower Carnation Creek watershed is Numukamis 1 reserve land (Figure 14).
- There are no Agricultural Land Reserves in the watershed.

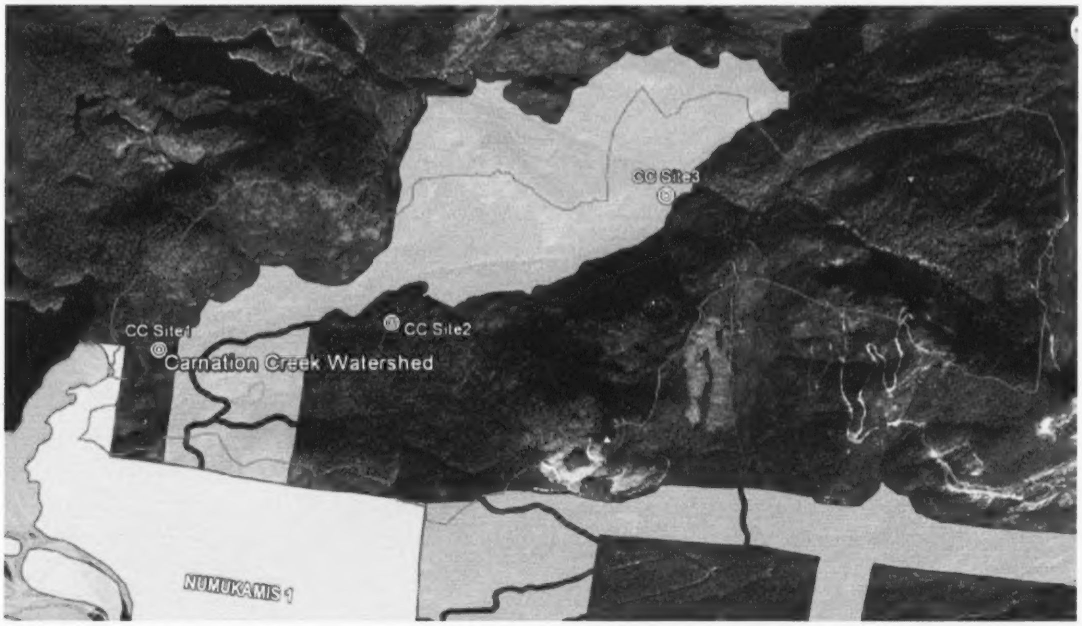

FIGURE 14 *Screen shot of First Nations treaty coverage from Google Earth. First Nations treaty area shaded pink; blue denotes reserve lands.*

BCGov Administrative Forest Boundaries WMS

- Carnation Creek is in the South Island Forest District, Coast Forest Region.
- Most of Carnation Creek is classified as provincial forest (see exceptions re: treaty settlement lands and Community Forest Licence).
- Carnation Creek is in TFL 44.

BCGov Licences and Permits WMS

- Aside from research, there are no special protected areas in the watershed.
- There are no range activities or licences in the watershed.
- There are two large managed licensed polygons in the watershed.
- There is a trapline boundary that runs through the lower part of the watershed.

BCGov Mining and Petroleum WMS

- No activities are highlighted in the watershed.

Proposed independent power projects

- There are no independent power project applications in the Carnation Creek watershed. There is one application in review in the adjacent Sarita River watershed (www.ippwatch.info/gmap/map.php).

Land use summary The search of titles and licences reveals no registered agricultural, range, or mining uses in the watershed. The land ownership is varied: it is primarily provincial forest, under TFL 44, with a smaller proportion of private and reserve lands. It can be concluded that the watershed is likely valued for trapping, hunting, and traditional uses by the local First Nations and that the primary land disturbance is forestry-based. Peter Tschaplinski was contacted (whom we located through the document search), who informed us that the watershed is an active research installation. Almost 60% of the watershed has been disturbed. The table of descriptive watershed data can now be completed (Table 13).

TABLE 13 *Descriptive watershed characterization for Carnation Creek*

Watershed size (km^2)	11.3	**Length of watershed (km)**	7
Location	West coast Vancouver Island	**Width of watershed (km)**	2
Relief (m)	0-855	**Number of stream crossings**	16
Biogeoclimatic zone(s)	Coastal Western Hemlock	**Length of mainstem (km)**	7.80
Land uses (%)	Research and forestry	**Length of tributaries (km)**	10.58
TFL/TSA	TFL 44	**Total length of all channels (km)**	18.38
Forest District/Region	South Island Forest District, Coast Forest Region	**Length of roads (km)**	28.34
Total disturbed area (km^2)	6.7 (59.2% of watershed area)	**Lake area (ha)**	1.6
Land ownership	Provincial forest, treaty settlement lands, small private portions	**Wetland area (ha)**	2.5
		Glacier area (ha)	0

2.8 Potential Effects of Land Use on Monitoring Sites

Water temperature There are no major wetlands or lakes upstream of any of the proposed monitoring sites. There are some elevation differences that could influence water temperature measurements. Water temperatures would mostly follow the cycle of seasonal air temperatures (although it is not known how contributions of groundwater could affect water temperatures). Any potential effects of forestry on the stream channel (widening and vegetation replacement) will have to be further examined. Widening of the channel is likely, given the extent of forest disturbance shown in the Google Earth image and the apparent lack of riparian reserves. Based on the flow data (flow drops to 0.004 m^3/s at Site 1), some upper sites could have discontinuous flow or could be dewatered in the dry season. The installation of air temperature loggers at each site to determine if dewatered conditions are occurring (i.e., to determine when the air temperatures are equal to the temperatures recorded on the stream temperature logger) is recommended.

Stream discharge Carnation Creek is in a rainfall-dominated hydrologic regime. Flows will be high in the winter and low in the summer, contingent upon the seasonal weather. In examining the three proposed sites, Site 1 could potentially be affected by tidal influence; therefore, it is flagged for field verification. The vegetation at Carnation Creek has been dramatically altered (~60% cut) over an unknown period of time. While the current equivalent clearcut area is unknown, an examination of the forest cover revealed that Site 2 is the least affected by vegetation modifications and potential drainage diversions via roads and stream crossings. Site 3 has minimal influence due to roads and stream crossings, and has only four tributaries (two of which are low gradient). Site 1 is close to the end of the watershed outlet and therefore will be influenced by all past land use effects. If sediment and channel issues are prevalent, Site 1 would potentially experience the most changes in bed elevations (scour and fill). This instability would demand more frequent field visits to maintain rating curve baselines or examine changing water levels over time. Overall, it is expected that certain aspects of the flows in Carnation Creek have been affected by past disturbances, that the Carnation Creek watershed is somewhere along a continuum of recovery, and that each of the three proposed sites is exposed to different hazards that may make site visitation requirements different among the proposed locations.

PART 3: DESKTOP CHARACTERIZATION OF CARNATION CREEK WATERSHED

The following watershed description is based on the information gathered using the template provided in section 2 of this report. Only information derived from this desktop approach has been included. This write-up is provided as an example presentation of information collected.

3.1 General Watershed Description

Carnation Creek is a small, 11.3 km^2 watershed located on the west coast of Vancouver Island near the town of Bamfield (Figure 15, Table 14). The watershed is situated in the South Island Forest District in the Coast Forest Region. The land ownership is varied: it is primarily provincial forest under TFL 44, and treaty settlement lands (Huu-Ay-Aht First Nations), but includes a smaller portion of private and reserve lands (Numukamis 1). There are no registered agricultural, range, oil/gas, independent power projects or mining uses in the watershed. The watershed is used primarily as an experimental research site. Research was initiated in the early 1970s to study the effects of land disturbance on anadromous and resident salmonids (P. Tschaplinski, B.C. Min. Environ., pers. comm., Feb. 14, 2013). Aside from research, the watershed is valued primarily for forestry, but trapping, hunting, and traditional uses are additional recognized values. Three sites have been selected for our water quality monitoring study (Figure 15).

FIGURE 15 *Carnation Creek watershed and proposed water monitoring sites. Red line denotes watershed boundary, yellow lines are roads, blue lines are streams.*

TABLE 14 *Summary of Carnation Creek watershed characteristics*

Watershed size (km²)	11.3	**Length of watershed (km)**	7
Location	West coast Vancouver Island	**Width of watershed (km)**	2
Relief (m)	0–855 m	**Number of stream crossings**	16
Biogeoclimatic zone (s)	Coastal Western Hemlock	**Length of mainstem (km)**	7.80
Land uses (%)	Research, forestry	**Length of tributaries (km)**	10.58
TFL/TSA	TFL 44	**Total length of all channels (km)**	18.38
Forest District/Region	South Island Forest District, Coast Forest Region	**Length of roads (km)**	28.34
Total disturbed area (km²)	6.7 (59.2% of watershed area)	**Lake area (ha)**	1.6
Land ownership	Provincial forest, treaty settlement lands, small private portions	**Wetland area (ha)**	2.5
		Glacier area (ha)	0

The watershed is located in the Coastal Western Hemlock biogeoclimatic zone. Vegetation modifications from past forest land management have been

extensive (Figure 16). Analysis of images from two different time periods reveals that approximately 4.6 km^2 of original old-growth forests likely remain in the Carnation Creek watershed (imagery dates unknown). Approximately 59% of the watershed's original vegetation has been harvested or disturbed in some manner. There has been no new harvesting in the watershed since the mid-1990s (P. Tschaplinski, B.C. Min. Environ., pers. comm., Feb. 14, 2013). Comparison of the images also reveals that the area of lake foreshore and wetlands has remained fairly constant over this time period, which indicates stability in these features.

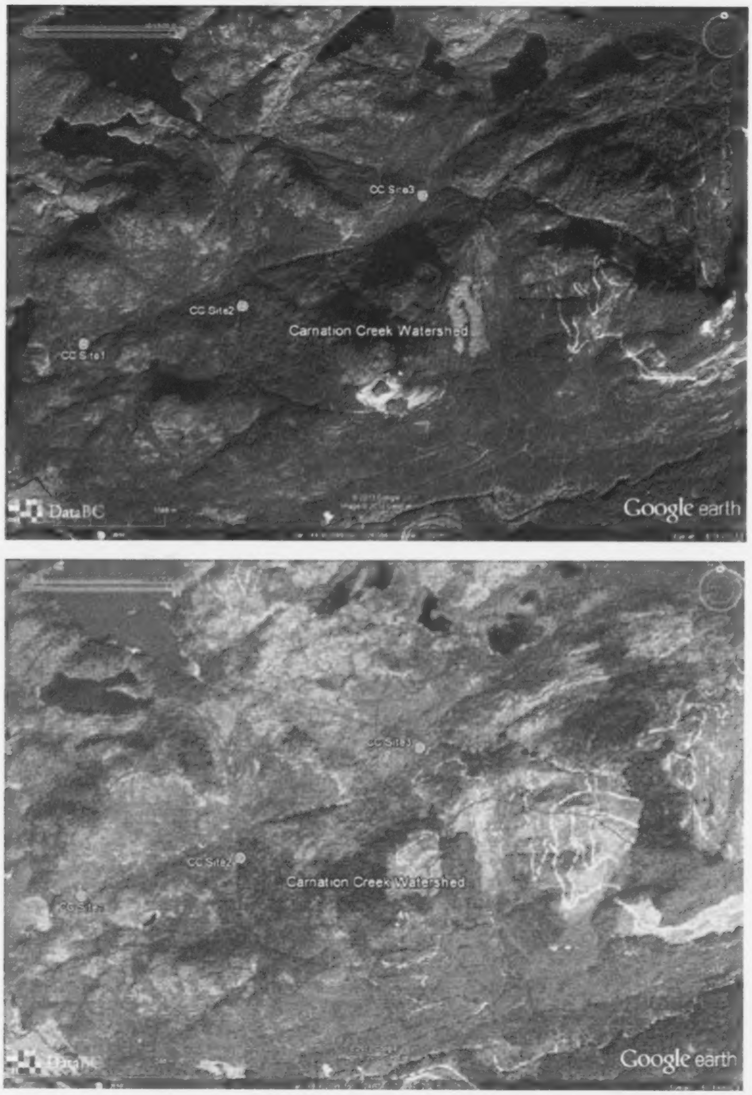

FIGURE 16 *Upper image: current Carnation Creek Google Earth image. Bottom image: historic Carnation Creek imagery (dates unknown). Red line denotes watershed boundary.*

3.2 Carnation Creek Climate Characteristics

Climate normal data (1971–2000) for Carnation Creek were obtained from Environment Canada's Climate Data website (Tables 15 and 16). Three climate-change emissions scenarios and modelled climatic information for two elevations (3 m and 680 m) were developed using Climate BC (Table 17).

The climate of Carnation Creek appears to be very typical of a coastal British Columbia watershed. The normalized mean annual temperature is 9.6°C. July and August are the warmest months at Carnation Creek (15–16°C), while December, January, and February (4–5°C) are the coldest months on average (Tables 15 and 16).

TABLE 15 *Annual and January–June climate normals for Carnation Creek CDF*

Carnation Creek CDF	Annual	Jan.	Feb.	Mar.	Apr.	May	June
Daily average temperature (°C)	9.6	4.4	5.1	6.7	8.5	11.1	13.3
Daily maximum temperature (°C)	13.6	7.4	8.5	10.8	13.0	15.5	17.7
Daily minimum temperature (°C)	5.6	1.4	1.6	2.6	3.9	6.6	9.0
Rainfall (mm)	2854.0	375.9	373.5	332.0	188.1	140.6	101.2
Snowfall (cm)	21.6	4.1	8.4	1.0	0.4	0	0
Precipitation (mm)	2875.6	380.0	381.9	333.0	188.5	140.6	101.2

TABLE 16 *July–December climate normals for Carnation Creek CDF*

Carnation Creek CDF	July	Aug.	Sept.	Oct.	Nov.	Dec.
Daily average temperature (°C)	15.1	15.5	14.2	10.6	6.3	4.3
Daily maximum temperature (°C)	19.5	20.0	19.0	14.7	9.4	7.2
Daily minimum temperature (°C)	10.6	11.1	9.4	6.3	3.1	1.4
Rainfall (mm)	63.7	68.6	115.5	283.1	416.2	395.4
Snowfall (cm)	0	0	0	0.1	1.3	6.6
Precipitation (mm)	63.7	68.6	115.5	283.2	417.5	402.0

The watershed receives approximately 2900 mm of precipitation annually near the ocean. Mean annual precipitation in the watershed increases with elevation from approximately 3000 mm to roughly 4000 mm (Table 17). Modelled precipitation at the upper elevations likely adds 500–1000 mm to the annual precipitation total (Table 17). Snow plays a minimal role in the seasonal pattern of precipitation and is estimated to be only 2–7% of the modelled average annual total amount (Table 17). There is a great deal of variability in the mean annual precipitation values among the few years examined. The lowest mean annual precipitation was 1866 mm (1985), while the highest recorded was almost double that value at 3573 mm (1974). Annual precipitation at Carnation Creek is quite variable between dry and wet years.

TABLE 17 *Modelled climate and climate change data for Carnation Creek at 3-m and 680-m contours from Climate Western North America*

	Lower Carnation Creek at 3-m contour				Upper Carnation Creek at 680-m contour			
	Baseline (current) 1971–2000	HadGEM A1B run 1 (hot/dry)	CGCM3 A2 run 4 (warm/ very wet)	HadCM3 B1 run 1 (cool/wet)	Baseline (current) 1971–2000	HadGEM A1B run 1 (hot/dry)	CGCM3 A2 run 4 (warm/ very wet)	HadCM3 B1 run 1 (cool/wet)
Mean annual temp. (°C)	10.1	14.7	13.2	12.1	8	12.6	11.1	10
Mean annual PPT[a] (mm)	2998	3267	3598	3081	3924	4284	4709	4037
PPT as snow (mm)	69	14	20	52	271	57	82	202
Winter PPT (mm)	1176	1262	1382	1209	1527	1640	1794	1573
Spring PPT (mm)	682	714	844	686	904	944	1115	908
Summer PPT (mm)	237	121	212	152	309	157	274	198
Fall PPT (mm)	903	1170	1161	1033	1184	1543	1526	1358

a PPT: precipitation

The hydrologic regime of Carnation Creek is rain-dominated and strongly coupled to seasonal weather patterns. The biggest accumulations of snow occur during the winter (January/February/March). Most of the yearly precipitation falls from September to May, while only 8% falls during the summer months (June–August).

Projected climatic changes Under a changing climate, both mean annual temperature and mean annual precipitation are expected to increase in the future (Table 17). Mean annual temperature could increase up to 4.5°C near the ocean (from 10.1 to 12.1–14.7°C), and by a similar amount (from 8 to 10–12.6°C) at 680 m elevation in the upper watershed. Increased mean annual temperatures may have an effect on streamflow, vegetation, water quality, and, ultimately, aquatic processes. Across all three modelled scenarios, summer precipitation amounts are forecast to decrease in the future. Summer precipitation is forecast to decrease from 237 to 121–212 mm near the estuary and from 309 to 157–274 mm in the upper watershed. A decrease in summer precipitation will likely exacerbate existing low summer flow conditions, which could influence water quality parameters and aquatic life in Carnation Creek.

3.3 General Hydrology and Drainage Characteristics

Drainage characteristics Carnation Creek is a natural flowing system with no points of diversion or regulation. The watershed lies approximately northeast to southwest, and ranges in elevation from sea level to 855 m. The total length of Carnation Creek's mainstem is approximately 8 km (Table 14), and there are numerous steep tributaries and side slopes along its length (Figure 17). The total measured stream channel length calculated from Google Earth is 18 km. There are relatively few stream crossings in the water-

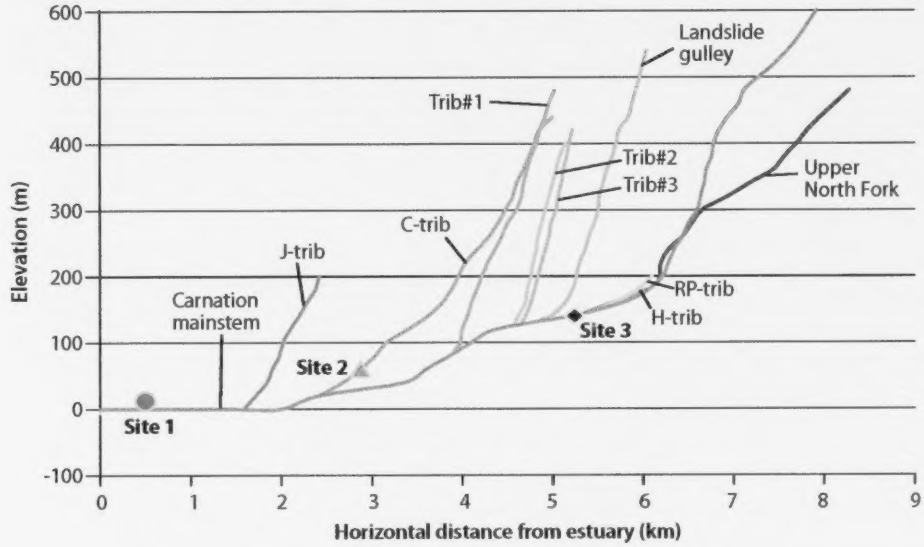

FIGURE 17 *Longitudinal profile of Carnation Creek and tributaries created from Google Earth.*

shed. In total, there are at least 16 stream crossings along the approximately 28 km of roads in the watershed. Only one of these stream crossings spans the mainstem, in the upper reaches of the watershed. It is unknown to what degree these historic stream crossings and roads are active/deactivated.

There is a small lake (1.6 ha) near the ocean and one small wetland (2.5 ha) that drain into the lowest tributary (Figure 15). Based on Google Earth, these features drain into Carnation Creek immediately at the creek's confluence with its estuary. Given the location of the lake and wetland in the watershed, these features will probably have no effect on the general flow characteristics of the stream.

The watershed geology is composed of granodioritic intrusive rocks (Island Plutonic group) and alkaline volcanic rocks (Bonanza Group). There is no mapped karst within the watershed. It is unknown to what extent groundwater contributions or preferential flow affect discharge in the watershed. There are no glaciers, and low annual snow accumulation precludes the formation of hybrid rain-snow-discharge regime characteristics. As a result, Carnation Creek is a rain-dominated watershed. However, there are likely periods in the winter when episodic snow accumulation and subsequent melt increases the magnitude of winter storm events.

Flow characteristics—annual discharge Two WSC stations were identified within the Carnation Creek watershed (Carnation Creek at the mouth – 08HB048 and Carnation Creek at 150-m contour – 08HB069). Historical daily average discharge data for the lowest-elevation station were obtained from WSC. Median monthly, mean monthly, mean maximum monthly, and mean minimum monthly flows are summarized in Table 18 and Figure 18. The highest monthly flows occur from November through January, while the lowest monthly flows typically occur in July, August, and September.

The overall mean annual discharge at Carnation Creek is 0.813 m^3/s, and, historically, the yearly mean has ranged from 0.430 to 1.13 m^3/s (Figure 19).

TABLE 18 *Median, mean, mean maximum, and mean minimum monthly and annual discharge (m^3/s) at Carnation Creek at the mouth – 08HB048*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Median (m^3/s)	0.696	0.543	0.536	0.365	0.176	0.108	0.055	0.031	0.061	0.221	0.789	0.719	0.232
Mean (m^3/s)	1.610	1.270	1.080	0.691	0.377	0.229	0.129	0.131	0.209	0.841	1.710	1.530	0.813
Mean max. (m^3/s)	3.360	3.040	2.410	1.450	0.948	0.772	0.615	1.340	0.841	2.310	4.040	2.610	
Mean min. (m^3/s)	0.184	0.184	0.279	0.070	0.062	0.038	0.013	0.007	0.010[a]	0.025	0.469	0.492[a]	

a Occurs more than once.

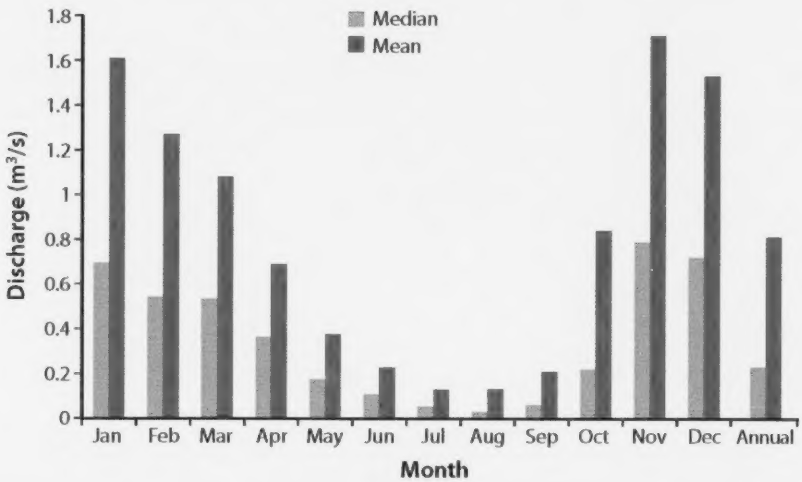

FIGURE 18 *Mean and median monthly/annual discharge (m^3/s) data for Carnation Creek at the mouth – 08HB048. Source: Water Survey of Canada.*

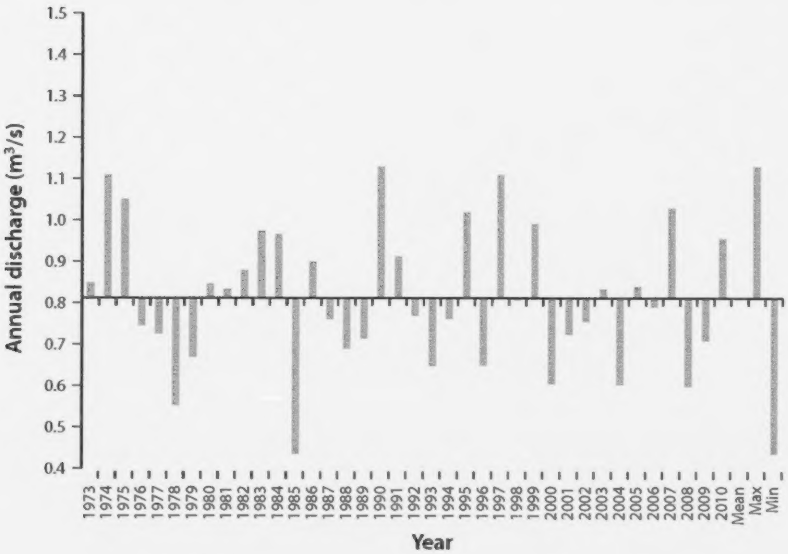

FIGURE 19 *Analysis of wet vs. dry years based on the mean annual discharge (m^3/s) for Carnation Creek at the mouth – 08HB048, from 1973 to 2010.*

The annual time series of mean annual discharge plotted at the 0.813 m^3/s level depicts years of below-average and above-average runoff (Figure 19).

Flow characteristics—low flows The lowest mean/median monthly flows, as driven by a lack of seasonal precipitation, typically occur in July and August (Table 18). Low flows usually occur anytime between July and October, but have occurred once in December (December 12, 2009). Low flows, therefore, can occur during one of the wettest times of the year in this watershed. Minimum instantaneous flows of 0 m^3/s have been observed a few times in the record, but the lowest average daily flow was recorded on August 5, 1985 (0.003 m^3/s).

Monthly duration analysis of daily flows was performed using the HEC-SPP software package (Table 19). The results show that while instantaneous low flows may dip down to zero, the occurrence of these values on a daily basis (sorted by month) is exceedingly rare (99% of the values on record for August are >0.004 m^3/s). It is not known to what extent or at what water level streamflow becomes intermittent along the channel profile.

Table 19 also illustrates that the mean monthly values presented in Table 18 may overestimate the "usual amount" of water available in Carnation Creek. For example, the mean August flow is 0.131 m^3/s, whereas the median daily August flow is 0.031 m^3/s. Table 19 shows that approximately 10–11% of the daily flow values on record for August have equalled or exceeded the mean August flow level of 0.131 m^3/s. On a weekly basis, the 7-day, 5-year low flow (7Q5) in Carnation is 0.009 m^3/s, and the 7-day, 10-year low flow (7Q10) is 0.006 m^3/s (Table 20).

TABLE 19 *Analysis of monthly discharge (m^3/s) exceedances for Carnation Creek at the mouth – 08HB048. Bold font indicates the median values.*

% of time exceeded	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
99	0.085	0.066	0.097	0.054	0.025	0.019	0.008	0.004	0.007	0.007	0.036	0.031
95	0.113	0.097	0.127	0.087	0.036	0.028	0.014	0.008	0.011	0.017	0.090	0.103
90	0.140	0.128	0.160	0.112	0.053	0.036	0.018	0.013	0.016	0.026	0.142	0.139
85	0.181	0.153	0.195	0.136	0.072	0.046	0.022	0.015	0.019	0.034	0.204	0.185
80	0.224	0.179	0.224	0.164	0.086	0.054	0.025	0.016	0.023	0.049	0.255	0.237
75	0.265	0.209	0.258	0.191	0.096	0.063	0.028	0.018	0.026	0.065	0.320	0.279
70	0.310	0.244	0.296	0.218	0.109	0.071	0.031	0.020	0.030	0.085	0.385	0.342
65	0.366	0.297	0.334	0.255	0.122	0.081	0.035	0.022	0.036	0.117	0.455	0.422
60	0.452	0.352	0.378	0.283	0.136	0.089	0.040	0.024	0.042	0.135	0.542	0.504
55	0.568	0.444	0.441	0.324	0.154	0.099	0.048	0.027	0.051	0.170	0.659	0.595
50	**0.696**	**0.543**	**0.536**	**0.365**	**0.176**	**0.108**	**0.055**	**0.031**	**0.061**	**0.221**	**0.789**	**0.719**
45	0.874	0.659	0.626	0.425	0.197	0.122	0.062	0.037	0.074	0.288	0.973	0.873
40	1.060	0.799	0.732	0.480	0.229	0.135	0.070	0.040	0.085	0.372	1.180	1.040
35	1.290	0.960	0.865	0.549	0.263	0.151	0.080	0.046	0.098	0.481	1.406	1.233
30	1.606	1.158	1.080	0.636	0.309	0.171	0.093	0.060	0.113	0.631	1.737	1.503
25	1.982	1.450	1.272	0.759	0.381	0.200	0.102	0.068	0.138	0.836	2.147	1.890
20	2.516	1.874	1.580	0.948	0.476	0.247	0.117	0.078	0.187	1.230	2.590	2.270
15	3.131	2.330	1.951	1.207	0.638	0.320	0.140	0.095	0.282	1.593	3.140	3.001
10	4.193	3.306	2.531	1.700	0.878	0.476	0.193	0.139	0.443	2.501	4.130	3.972
5	6.220	4.954	3.640	2.579	1.472	0.886	0.383	0.374	0.880	3.820	6.098	5.676
2	9.765	7.270	5.877	3.884	2.517	1.654	0.838	1.075	1.625	6.034	10.518	8.614
1	11.342	9.482	7.644	4.570	3.230	2.321	1.554	2.175	2.407	8.434	13.459	9.768

TABLE 20 *Low flow frequency analysis results for Carnation Creek at the mouth – 08HB048*

Return period (years)	Yearly probability of occurrence (%)	1-day (m^3/s)	3-day (m^3/s)	7-day (m^3/s)
1.25	80	0.034	0.034	0.036
2	50	0.017	0.017	0.018
5	20	0.008	0.009	0.009
10	10	0.006	0.006	0.006
20	5	0.004	0.005	0.005
50	2	0.003	0.003	0.003
100	1	0.002	0.003	0.003
200	0.5	0.002	0.002	0.002

Flow characteristics—peak flows Rain-on-snow events may occur episodically throughout the winter, thereby enhancing peak flow generated by storm events. Runoff in Carnation Creek typically occurs rapidly (flashy) in response to rain and similarly tends to drop off abruptly upon the cessation of precipitation (Figure 20). The magnitude and duration of streamflow peaks in Carnation Creek are strongly controlled by the duration and intensity of precipitation. The maximum instantaneous discharge on record occurred on January 3, 1984 (65.1 m^3/s), and the maximum daily discharge on record is 24.4 m^3/s, which occurred on November 10, 1990. Instantaneous and daily maximum peak discharge (1974–2010) were analyzed in HEC-SSP. The 2-year daily maximum flood was 13.34 m^3/s, while the instantaneous 2-year maximum was 26.62 m^3/s (Figure 21).

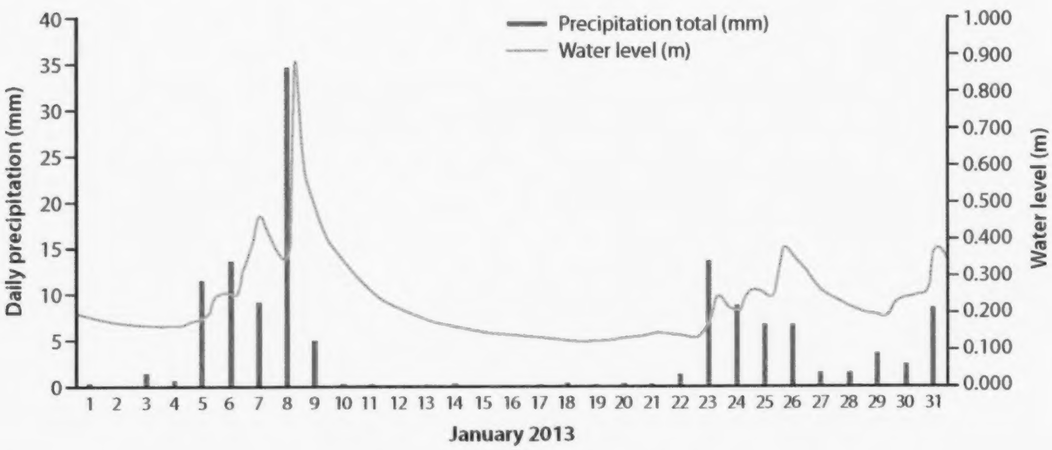

FIGURE 20 *Daily precipitation (mm) at Bamfield Marine Station vs. water level (m) at Carnation Creek, January 1–31, 2013.*

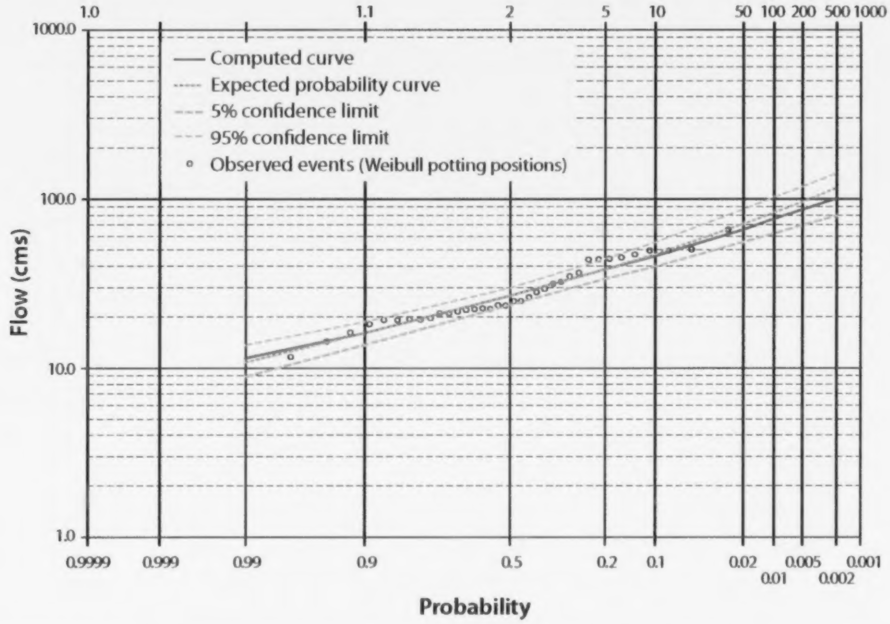

FIGURE 21 *Instantaneous maximums discharge (1 cms = 1 m³/s) vs. return period/probability, Carnation Creek at the mouth – 08HB048.*

Flow characteristics—disturbance drivers An analysis of low-flow/peak-flow trends, as driven by climatic and land disturbance drivers, was not performed for this report. Given the approximately 60% past disturbance to the watershed, it is very likely that flow modifications have occurred and are contained within the hydrometric data record. This would apply to both low-flow and peak-flow discharges at Carnation Creek. The timing of flows may also have been altered. There are 28 km of roads with impermeable surfaces. This total distance is 10 km more than the total stream channel network measurements. It is possible that roads are intercepting subsurface flow through the hillslopes and redirecting it via ditch and road flow into natural surface drainages. This may reduce the time it takes water to reach the stream channels in response to precipitation events (e.g., flashier response to precipitation).

3.4 Potential Effects of Land Use on Proposed Sites/Monitored Parameters

Sediment The morphology of the Carnation Creek watershed is well suited to moving sediment from the hillslopes directly into the stream channel. There are a number of very steep tributaries and gullies in the upper mainstem that could act as pathways (Figure 17). There are also several places where the tributaries/gullies join the mainstem and lose confinement; these are possible fan locations. The 28 km of road and 16 stream crossings should be evaluated for sediment yield potential.

The proposed location of the three monitoring sites (Figures 15 and 17) shows that Sites 3 and 2 have the least amount of exposure to cumulative sediment hazards, while Site 1 has the greatest hazard. There are two stream crossings above Site 3. No stream crossings/roads will affect Site 2, and 13 out of 16 stream crossings could affect measurements at Site 1. Site 2 is likely the

best location as a background site, given the stability in forest cover and absence of upstream influence of roads/stream crossings. Site 1 is probably best suited to measuring cumulative disturbance response. These recommendations will be finalized after field verification.

Water temperature There are no major wetlands or lakes upstream of any of the proposed monitoring sites. There are some elevation differences between the proposed monitoring locations that will probably influence measurements. Water temperatures will probably follow the cycle of seasonal air temperatures. The potential effects of forestry on the stream channel (widening and replacement vegetation) may exacerbate the maximum and minimum water temperatures in Carnation Creek. Widening of the channel is very likely in Carnation Creek, given the extensive forest cover disturbance and apparent lack of riparian reserve zones. The low-flow characteristics of Carnation Creek may result in dewatered conditions at one of more of the proposed sites (given that the minimum discharge is approximately 0.004 m^3/s near Site 1). It is expected that some upper sites could become discontinuous; therefore, it is recommended that air temperature loggers be installed at each site to enable a determination of dewatered conditions (i.e., to determine when the air temperatures are equal to the temperatures recorded on the stream temperature logger).

Discharge Carnation Creek is in a rainfall-dominated hydrologic regime with high flows in the winter and low flows in the summer. In examining the three proposed sites, Site 1 could potentially be affected by tidal influence, which is flagged for verification in the field. The vegetation at Carnation Creek has been dramatically altered (~60% cut). While the current equivalent clearcut area is unknown, the forest cover at Site 2 is the least affected by vegetation changes and potential drainage diversions via roads and stream crossings. Site 3 has minimal influence from roads and stream crossings, and has only four tributaries above it (two of which are low gradient) (Figure 17). Site 1 is close to the end of the watershed outlet, and therefore will be influenced by all past land use effects. If sediment and channel issues are prevalent, Site 1 will probably experience the most changes in channel bed elevations (scour and fill), and hence, instability in establishing a baseline from which to create a rating curve or examine changing water levels over time. Overall, Carnation Creek is somewhere along a continuum of recovery, and certain aspects of the hydrologic regime will have been affected, which will subsequently influence each of the three proposed sites differently. This demands that consideration be given to planning field maintenance of data loggers and that data downloads be tailored to each monitoring location.

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7Q10	7-day, 10-year low flow
7Q5	7-day, 5-year low flow
CDF	Coastal Douglas-fir
CWH	Coastal Western Hemlock
EcoCat	Ecological Reports Catalogue
EMS	Environmental Monitoring System
FLNRO	B.C. Ministry of Forests, Lands and Natural Resource Operations
HEC-SSP	U.S. Army Corps of Engineers, Hydrologic Engineering Center Statistical Software Package
KML	Keyhole Markup Language
MOE	B.C. Ministry of Environment
PCDS	Provincial Climate Data Set
PCIC	Pacific Climate Impacts Consortium
TFL	Tree Farm Licence
TSA	Timber Supply Area
WMS	Web Map Service
WNA	Western North America
WSC	Water Survey of Canada